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**GEOLOGICAL SURVEY OF CANADA.**

ALFRED R. C. SELWYN, DIRECTOR.

**NOTES**

ON

**IRON AND IRON ORES,**

BY

**T. STERRY HUNT, LL.D., F.R.S.,**

CHEMIST AND MINERALOGIST TO THE SURVEY,

EXTRACTED FROM A REPORT

ADDRESSED TO

**SIR WILLIAM E. LOGAN, F.R.S.,**

LATE DIRECTOR OF THE SURVEY.

*From the Reports of the Geological Survey of the Dominion of Canada for 1867-69.*



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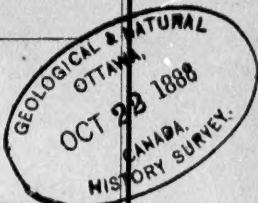
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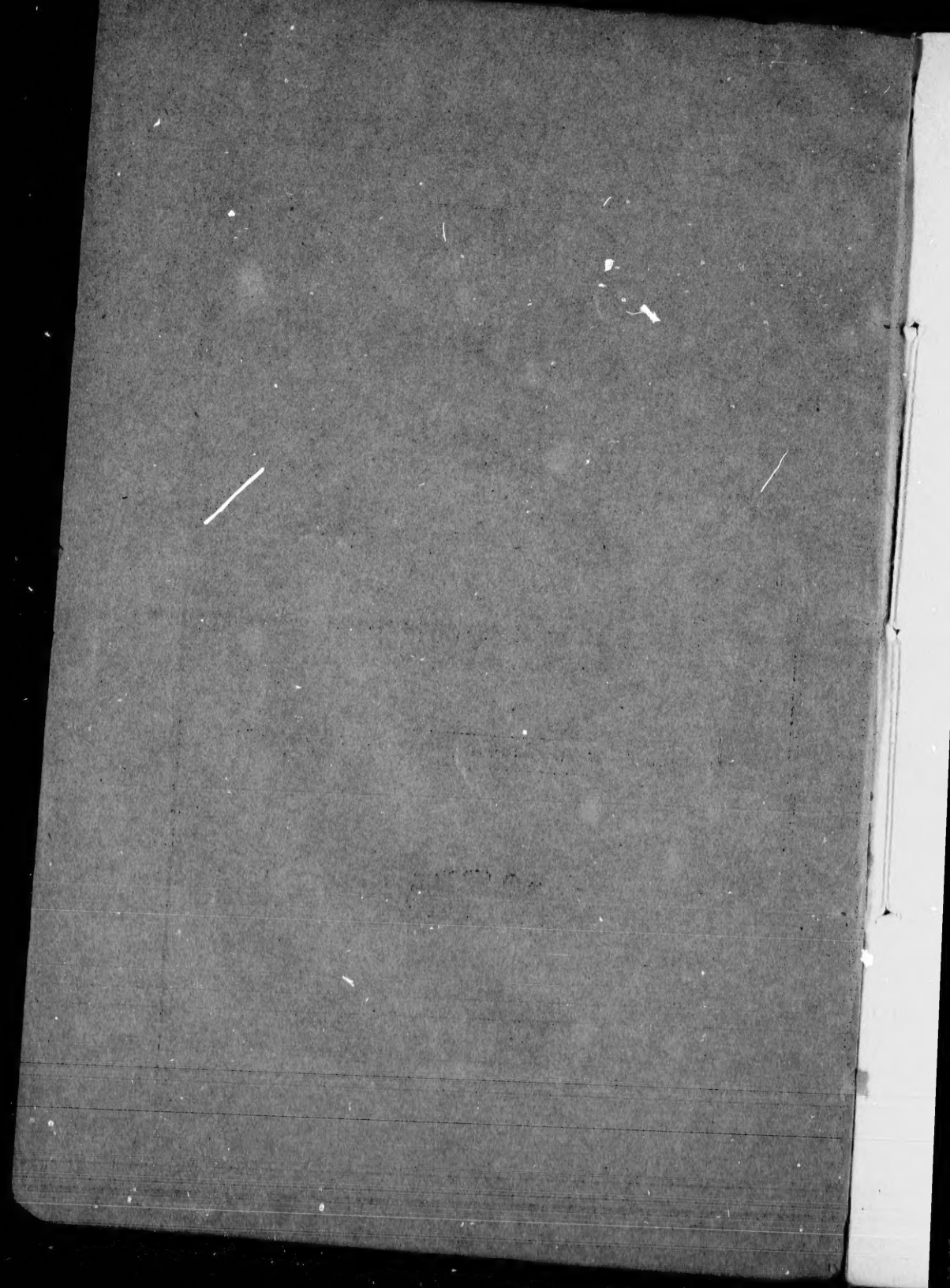
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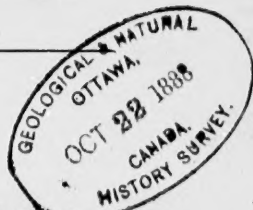
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# NOTES ON IRON AND IRON ORES,

BY

T. STERRY HUNT, LL.D., F.R.S.

The following pages are extracted from the Reports of the Geological Survey of Canada for 1867-69, and form a part of the author's report,\* dated Nov. 1, 1869, and addressed to Sir William E. Logan, F.R.S., late director of the Geological Survey of Canada. They have been written especially for the design of affording information with regard to some of the iron ores of the provinces of Ontario and Quebec, and the best modes of working them. In a subsequent report, it is proposed to continue the subject, and to add details respecting the ores of New Brunswick and Nova Scotia. The reader will find, prefixed, a table of contents, which will serve to shew the points herein discussed.

The iron ores of the Laurentian system are, for the greater part, of the magnetic species, and are similar in geological relations and in mineralogical characters to the ores which occur in the same system in northern New York, and in the Highlands of southern New York and New Jersey, where they have long been mined to a great extent. Similar ores, moreover, abound in Norway and Sweden, where they occur in rocks of the same age, and furnish great quantities of very pure iron, which is famous throughout the markets of the world. Having had opportunities at the Exposition at Paris, in 1867, to learn many facts about the iron-industry of these countries, I have thought it would be well to embody some of them in the present report, as likely to prove valuable to the mining interests of the Dominion. A large portion of both Norway and Sweden is occupied by old gneisses of the Laurentian system, which also comprise the greater part of the provinces of Ontario and Quebec. This geological resemblance, with somewhat similar conditions of soil and climate, gives to any facts relating to the mineralogy and metallurgy of those northern regions, a special interest to the people of Canada.

Ores of Norway  
and Sweden.

In the year 1865, according to official data, there were extracted in Sweden 492,474 tons of iron ore, employing 5,062 workmen. The mines or openings from which this amount of ore was raised, are stated to be 524 in number, and some of them are evidently worked on a very small scale. The workings are ordinarily by open cuttings upon the beds or masses of ore, which are described as being very generally in a nearly vertical atti-

Working,

\* The numbers at the heads of the pages, in the outer corners, commencing with 245, correspond with the pages of the volume from which these notes are extracted, and are referred to in the text; while the numbers in the inner corners are those of the prefixed table of contents.



tude, and in solid crystalline rock, requiring but little support by timbering. The mineral is mined with powder, although nitro-glycerine has been tried to some extent. The pay of the workmen ranges from thirty to fifty cents per day, and the cost of the ore, when raised, is said to vary from one to two dollars for the ton of 1000 kilogrammes (2205 pounds avoirdupois). With the exception of a small quantity carried into Finland, the whole of this ore is smelted in the country. The production of iron ores in Norway is much less than Sweden; about 22,000 tons are raised annually, of which 2500 tons are exported, the remainder being smelted in blast-furnaces with charcoal. At one of the most important of these, that of Laurvig, where a remarkably fine iron is made for the American market, the cost of the ore at the furnace is stated at \$1.80 the ton.

Charcoal  
making.

In Sweden, and in Norway, charcoal is the only fuel employed for the reduction of the iron ores, except in some rare instances, where a mixture of charcoal and dry wood has been used in the blast furnace. Careful trials, however, appear to show that this admixture offers no advantages over the use of charcoal alone. About one-third of the surface of Sweden is covered with forests, which constitute an important source of wealth to the country, and of late years have been the object of care and attention, with a view to a due economy of fuel and lumber. The trees of the Swedish forests, with the exception of the southern peninsula, where oak and beech are met with, are chiefly of coniferous or soft-wooded species, and the pine of the country (*Pinus sylvestris*) is the one principally used for metallurgical purposes, the timber being sawn or hewn for lumber, while the branches are employed for the manufacture of charcoal. The wood is cut in the months of March and April, before the rising of the sap, and is divided into lengths of about eight feet, which are allowed to dry during the summer months. The charcoal-burning takes place in October and November, and is generally carried on in circular piles about twelve feet high and from twenty to thirty feet or more in diameter. The burning of a pile lasts from two to three weeks from the time of kindling. Experience has shown, in Sweden, that the economy is much greater when the wood is laid upon its side in the piles than when placed on end. In the latter case the yield of charcoal is from 60 to 62 per cent. of the volume of the wood, while in the former it is not less than 70 per cent. According to a Report to the Swedish Minister of Agriculture, Commerce and Public Works, published in 1866, the average cost of labor for a pile yielding from twelve to thirteen tons of charcoal, is 84 francs, which is equal to about \$1.30 for the ton of 1000 kilogrammes. This price includes the cutting and drawing of the wood.

The cubic meter or stere of 35.317 cubic feet of pine charcoal in Sweden weighs from 142 to 145 kilogrammes, so that the ton of 1000 kilogrammes



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(2205 pounds) would measure very nearly 7 steres, or 247 cubic feet, and the weight of the cubic foot of charcoal would be a little over 4 kilograms, or 8.8 pounds, nearly. According to figures given by Grill, however, (Percy, *Metallurgy of Iron*, page 596) a ton of the charcoal used in the Lancashire hearths, in Sweden, measures not less than 297 cubic feet. In the American iron-regions charcoal is bought and sold by the bushel, which is an arbitrary measure of about five pecks, equal, according to Overman, to 2600 cubic inches, and according to Osborn to 2675 cubic inches, (the United-States standard, or Winchester bushel, measuring 2150.42 cubic inches.) Taking the latter figure, we find that the American charcoal-bushel of Swedish pine-charcoal would weigh a little over 13.5 pounds avoidupois.

Weights of  
charcoal.

The experiments of François, in the Pyrennees, give for the weight of the cubic meter of charcoal of beech and oak, from 218 to 235 kilogrammes, that of alder being 141, and that of pine and spruce from 152 to 173. He deduces as the mean for hard-wood charcoal 227, and for soft-wood, 170 kilogrammes, corresponding respectively to 21.9 and 16.4 pounds avoidupois for the charcoal-bushel as above. (Jules François, *Des Minerais de Fer*, etc., page 177.) The elaborate studies of Mr. Marcus Bull on the charcoal from North American woods, give the following as the weights, in pounds, of a bushel of dry charcoal from these kinds, among others: red cedar 12.52, white pine 15.42, yellow pine 17.52, white birch 19.15, and several varieties of maple and oak from 21 to 23 pounds.\* This last is confirmed by the observation of Mr. Kennedy, at the Hull Iron-works, who informed me that a bushel of mixed beech and maple, such as there used, weighed from 22 to 23 pounds.

The cubic meter is equal to about 22.8 charcoal-bushels of 2675 cubic inches, and the price of the cubic meter of charcoal, which reaches at some furnaces, \$1.30, is on an average, in Sweden, 85 cents, or about four cents the bushel. At the iron furnace of Laurvig, in Norway, the cost of good charcoal is said to from 60 to 70 cents the cubic meter.

Cost of coal.

In a few localities in Sweden, where water-courses afford facilities for floating the wood to the furnaces, the charring is effected in ovens of a peculiar construction, furnished with an arrangement for condensing the acid and tarry products given off during the process. The plan of one of these furnaces, shown at Paris, in 1867, was similar to that figured by Dr. Percy, on page 125 of his first volume on Metallurgy, in which will be found discussed in great detail, the whole subject of charcoal-burning, on pages 107-142.

\* These results were published in the Transactions of the American Philos. Society, for 1826, new series, pp. 1-60, and are reproduced in the American edition of Knapps Technology, i, 24.

Carrying fuel.

Although the Swedish ores vary considerably in their richness, it may be calculated that, in general, about two tons of ore are required for one ton of cast iron, to produce which are consumed on an average about a ton of charcoal. It is evident therefore that, for the same cost of production, the fuel can be transported much farther than the ore. Charcoal is often carried from localities where wood is abundant, to blast-furnaces in the vicinity of mines, a distance of twenty or thirty leagues. This is done in part by water or by rail, but for the transport of the ores from regions not easily accessible at other times, sledges are much used in the winter, which becomes the most favorable season for getting both the charcoal and the ores to the furnaces, which are generally as near as possible to the mines. In some cases the ores are carried for distances of ten or more leagues; but this is generally when there is a back-freight of iron or other materials. The wages of a carter, with his horse, vary from \$0.80 to \$1.40 per day, and the cost of transporting the ore is from  $6\frac{4}{5}$  to  $9\frac{6}{10}$  cents the ton for the English mile.

Law concerning mines.

The law with regard to mines in Sweden is as follows: The discoverer becomes the owner of one-half, while the other half remains the property of the owner of the land, who can work it by sharing the cost with the discoverer, or dispose of his share in the mine. A permission to work a new mine must be given by the magistrate; and if left unworked during a certain number of years, without obtaining a special authorization from the magistrate to do so, or without performing annually an amount of labor, stipulated as necessary to retain possession of the mine, the permission lapses, and the mine can be taken up again by another party on the same terms as a newly discovered one.

Many of these mines are worked on a small scale, by little proprietors, who sell their ore, or in other cases join their forces and construct, between them, a blast-furnace at a cost of from \$12,000 to \$14,000. Much of the iron manufactured in Sweden has, from the earliest period, been in the hands of peasants and small proprietors. The manufacture of cast iron in Sweden goes back about 200 years; previous to that time wrought iron was made from the ore by a direct method. Those regions where ore and fuel furnished conditions favorable to mining industry, were formerly constituted into districts, which were invested by the state with certain privileges, and subjected to certain restrictions, one of which was to export beyond their limits all the cast iron manufactured within their respective districts. All of these restrictions are now, however, abolished.

Blast-furnaces.

The total number of blast-furnaces in Sweden is about 300, of which 219 were in blast in 1865, and instead of being grouped together, as in some other countries, they are, with few exceptions, isolated; a single furnace being erected in some spot where a water-power and facilities

their richness, it may be required for one an average about a same cost of producing the ore. Charcoal to blast-furnaces in Sweden. This is done with the ores from regions used in the winter, with the charcoal and as possible to the cost of ten or more per ton of iron or other from \$0.80 to \$1.40 to 9 $\frac{1}{2}$  cents the

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300, of which together, as in ated; a single and facilities

of transportation are met with in proximity to forests sufficient to afford a supply of charcoal, the deposits of ore being pretty widely distributed. The amount of ore raised in 1865 has been already stated at 492,474 tons, employing 5063 workmen. The production of the various furnaces in the same year was 226,676 tons of cast iron, employing 3683 workmen, whose wages ranged from \$0.30 to \$1.40 per day.

The ores vary in richness from the nearly pure magnetic or specular ores, containing as much as 70 per cent of iron, to those yielding not more than 28 per cent. The Swedish ores and irons have been made the subject of very minute and extended chemical studies, with reference to the proper composition of the charges, the nature and quantity of fluxes to be added, the various impurities in the ores, and the influence of all these upon the quality of the iron. Foremost in importance are considered the influence of sulphur, phosphorus and manganese. Both sulphur and phosphorus are regarded as especially detrimental to the iron destined for the forge, or for the manufacture of steel, and from these impurities the Swedish ores are generally very free, when compared with the ores of England and France, a purity which they may be said to share in common with the Laurentian ores of North America. The observations which have been made with regard to the Swedish ores, in this respect will, therefore, for the most part, be equally applicable to our own. The sulphur of the Swedish ores is generally present in the form of pyrites or sulphuret of iron, and may be expelled by roasting at a red heat, which completely oxidizes this substance. If, however, carbonate of lime is present at the same time, a portion of sulphate of lime is formed, by which some of the sulphur is retained, and can only be removed by subsequent washing with water, in which the sulphate is slightly soluble. It does not appear whether the use of water is ever thus resorted to. The ingenious furnace of Westmann, by which the waste gases from the blast-furnace are employed to effect the roasting and desulphurizing of the ore, is said to have been found thoroughly efficient in Sweden, and is now in use at Ringwood, in New Jersey, in connection with a blast-furnace, by Messrs. Cooper, Hewitt and Co. In some cases the roasting of the ores in Sweden is two or three times repeated. The heat is so great that they are more or less softened, and show a commencement of fusion. The magnetic ores, after this process, appear to be more readily reduced than before, though the roasting seems, from the result of analyses at Fahlun, to have but little affected the state of oxydation of the iron. The favorable effect is probably due, in part, to the fissuring of the ore by the heat. The presence of even small portions of sulphur in wrought iron renders it, as is well known, brittle when hot, or red-short, as it is termed. For certain purposes, however, the presence of sulphur in cast iron is not objectionable. Thus, for casting

Composition of  
ores.

Sulphur.

Calcination.

cannon, according to Rinman, a very strong metal is obtained by adding to the charge a small amount of sulphuret of iron, and in general for this purpose a charge is preferred free from phosphorus, but somewhat sulphurous. The sulphur causes a larger proportion of carbon to remain in a combined state; a very tenacious mottled cast iron is obtained, holding about 0.09 per cent of sulphur, and the quantity may even rise to 0.30 or 0.50 per cent. The use of sulphurous ores, according to Rinman, like that of manganesian ores, enables us to obtain white iron when the furnace is running at its ordinary rate, and without any overcharge of ore.

Phosphorus.

Phosphorus, in like manner, though it renders wrought iron cold-short, gives to it a hardness which renders it peculiarly valuable for some purposes, as for boiler-plates, roofing-sheets, spades, shovels and hoes, and other utensils which are exposed to severe wear. In the metal for these, at least 0.1 per cent of phosphorus, and in that for fine castings as much as 0.5 per cent, is considered advantageous, as contributing in the latter case to give greater fusibility and fluidity to the melted metal. But for the manufacture of steel, phosphorus seems to exert a highly prejudicial influence, and it appears from carefully-made analyses of Swedish irons, that their value in the Sheffield market, where their relative fitness for the manufacture of steel has been determined by experience, is, as shewn by Rinman, directly in proportion to their freedom from phosphorus.

The amount of phosphorus in the ores of Dannemora, Bisberg, and some other of the Swedish mines does not exceed 0.005 per cent., while in some others, as Gellivara and Graengesberg, it rises to 1.3 and even 2.0 per cent. Some of these ores, like similar ores in northern New York, contain imbedded grains of phosphate of lime or apatite. It is, however, to be remarked that the whole of the phosphorus in the charge does not pass into the ores, and moreover, that the proportion of this element varies in different parts of the deposit, so that by a judicious admixture of the phosphuretted with purer ores, the resulting cast iron will not contain more than 0.15 per cent. of phosphorus, which does not render it unfit for ordinary uses.

Manganese.

Manganese is also conceived to exert an important influence, in more ways than one, upon the quality of iron. The Swedish ores not unfrequently contain a portion of this element, and when absent from any ore it is sought to be supplied by mixtures containing manganese. While the greater part of it passes into the slags, a certain portion remains in the cast iron, and to its presence it is customary to ascribe a peculiar fitness in the resulting malleable iron for the manufacture of steel. It is, however, remarked that manganese is often wanting, without any observed inferiority in the cast iron.

The presence of titanium, and its influence upon iron, is a subject which has

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of late been very much debated. While claimed by Mr. Mushet, and some others, to exert a special and most beneficial influence on the quality of steel, this is denied by others. When ores containing titanium are smelted, a small portion of this element, amounting in some cases to a little over one per cent., passes into the cast metal, and is said to increase its strength, besides giving it a peculiar mottled aspect. It seems, however, "doubtful whether any titanium remains in the bar iron or steel made from such pig iron, so that the improvement attributed to the use of titaniferous ore is probably due to some indirect action, rather than to the actual presence of titanium in the finished product. The evidence on this point is not sufficiently clear to allow of any positive conclusion being formed." To the above statement of Bauerman, I may add that I have failed to detect any titanium in bloom iron made by the direct method from an iron ore containing 16 per cent. of titanium, which will be described further on.

Some remarks upon the composition and the results of analyses of the Swedish ores may not be without value, as serving for comparison with the iron ores of Canada. The iron, both of Sweden and of Norway, is made, with but few exceptions, from ores of the magnetic species. That of the famous Dannemora district, which supplies a great number of blast-furnaces, and produces an iron regarded as superior to all others for the manufacture of steel, occurs as an irregular interrupted belt, a mile and a half in length, which is imbedded in crystalline limestone, with a kind of petrosilicious rock, and has been mined to a depth of more than 100 fathoms. The composition of different portions of the deposit presents considerable variation. Average specimens from one of the most important masses, sent to the Paris Exhibition in a roasted state, as prepared for the furnace, showed considerable admixtures of silica, lime and magnesia, with some alumina. The sum of the united protoxyd and peroxyd of iron for these two ores, was respectively about 54 and 68 per cent., equalling 38.5 and 48.6 per cent of metallic iron. These two ores were almost destitute of sulphur and phosphorus, and had the advantage, when mixed, of yielding a fusible slag without the addition of any limestone for flux. Others of the Swedish ores are much richer in iron than these, while others, still, are very much poorer. Thus, at Taberg, an ore is mined, which consists of magnetic iron disseminated through a serpentine, (sometimes described as a diorite), the magnetic oxyd constituting not more than one half of the mass. This ore, which contains at the same time, from 6 to 10 per cent. of titanac acid, yields only about 25 or 30 per cent of iron. It is melted with about one-fourth its weight of limestone as a flux, and gives a white mirror-like cast metal, which yields an iron much esteemed for wire-drawing. Fuel being cheap in the neighborhood, this ore is extensively mined and smelted. Bauerman states that attempts were made to

Titanium.

Dannemora  
ore.

Taberg ore.

treat this ore, previously dressed so as to yield 43 per cent of iron, but for this purpose it was necessary to bring it to such a finely divided condition, that it was judged better to smelt it in its natural state, the expense due to the increased consumption of fuel, being counter-balanced by greater facility in treatment. Besides this of Taberg, other similar ores have long been smelted in Norway and in Finland. The ore from the Cristine mine at Krageroë, in southern Norway, is described as a brilliant black titaniferous magnetite, not very strongly attracted by the magnet, and intermixed with grains of quartz, and of greenish-black hornblende, with a little magnetic pyrites. It contained no phosphorus, but gave by analysis 42.0 per cent. of metallic iron, besides 15.10 of titanio acid and 19.9 of silica, with a small amount of earthy bases. Inasmuch as many of our Canadian ores are more or less titaniferous, the following notes with regard to the smelting this and other titaniferous ores are of much interest. They are extracted from a communication by Mr. David Forbes, in the *Chemical News* for December 11, 1868.

Working  
titanic ores.

"The experience of the Scandinavian iron-masters has shown that the only objection to the use of titaniferous ores is that they are found to be more refractory in the blast-furnace, in proportion as they contain a greater percentage of titanio acid; and if much titanium is present they require a so much larger amount of charcoal to smelt them as not to render their employment profitable in a country where other ores free from titanium can be obtained at a reasonable rate. After considerable experience in smelting the ore of Krageroë, which yielded a very good iron, it was found unprofitable to smelt it alone, for the above reason; but its use was found beneficial when employed in about equal proportions with the other ores of the district, which were free from titanium." Mr. Forbes found, in his experience, that by employing a mixture of crushed quartz and limestone as a flux, when the proportion of titanium in the ore did not exceed eight per cent, or was reduced to this amount by admixture of ores free from titanio acid, no difficulty was experienced in working this ore cleanly and profitably. The iron produced was free from phosphorus, gave but a trace of sulphur, and only 0.05 of titanio acid, which was supposed to be mechanically present rather than chemically combined with the iron. Another very similar ore from Eger, which contained 38.89 per cent. of iron and 7.10 of titanio acid, was found to contain too much sulphur and phosphorus to be fit for bar iron, but yielded a good foundry-pig metal, which gave by analysis 0.26 of titanio acid. When smelted alone it was refractory, and did not yield a liquid slag, but it was readily fused when mixed, as at Krageroë, with ores destitute of titanium.

The experience of the iron-masters in New York, who have endeavored to smelt the titaniferous ores of Lake Champlain, generally in admixture



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with other ores, has been very unfavorable, but an attention to the above suggestions might probably enable them to overcome the difficulties hitherto encountered. Besides the great bed of ore at Bay St. Paul, holding nearly half its weight of titanio acid, Canada has large deposits of ores containing more or less titanium, some of which will be described farther on. In the *Geology of Canada*, page 501, I have shown that a massive granular titaniferous ore from St. François, on the Chaudière, in the province of Quebec, consists of a mixture of about two-thirds of nearly pure magnetic oxyd of iron, and one-third of a titanio iron or menaccanite holding not less than 48 per cent of titanio acid. The two are, however, readily separable by a magnet, and it is probable that by a magnetic separating machine it will be possible to make use of this and of similar ores for the preparation of iron in the direct way, to which the purified magnetic oxyd is well adapted. The iron sands, which contain a large admixture of titanio iron, will be noticed in their place.

Titanic ores.

In this connection I quote from Osborn's recently published volume on the *Metallurgy of Iron and Steel*, page 475, the following statements, which he gives as a communication from a Mr. Henderson, according to whom an ore from Norway, holding over 40 per cent of titanio acid, is now successfully smelted at Norton, in England, by a process patented by Player of New York. The ore is said to be smelted in small furnaces, with a blast at 1000° temperature; 2 tons of coal being required to 2½ tons of the ore, with 15 cwt. of limestone, and about 10 cwt. of basalt. The pig-metal thus produced is stated to contain very little carbon, and to be very easily puddled, producing a malleable iron of great tensile strength. Such ores are necessarily poor in iron, as compared with magnetic ores, and even if they can be readily smelted by the above treatment, it remains to be seen whether their use offers any real advantage.

#### ANALYSES OF SOME IRON ORES.

The bed of magnetic ore, which has long been known at Hull, is described in the *Geology of Canada*, page 674. The association of a portion of a red hematite with the magnetic ore, and of graphite with both, is described in the Report of the Survey for 1866, p. 216. Since then a large blast-furnace has been erected here, which for some time produced a superior quality of pig-iron; but the working has been since abandoned, the economic results not being satisfactory. The two samples whose analyses are here given had been prepared for that purpose by Mr. Kennedy, the director of the works, and selected so as to represent the average of the ore smelted. One of these, designated at the furnace as the red ore, was colored by an admixture of hematite, while the other was known as the black ore. The red ore gave as follows:—

Hull, Ontario.

Hull, red ore.	Peroxyd of iron.....	66.20	} = metallic iron 58.78.
	Protoxyd of iron.....	17.78	
	Oxyd of manganese.....	traces.	
	Lime, as silicate.....	.76	
	Magnesia, as silicate.....	.45	
	Carbonate of lime.....	2.66	
	Silica.....	10.44	
	Graphite.....	.71	
	Phosphorus...	.015	
	Sulphur.....	.280	
		<hr/>	
		99.295	

The black magnetic ore of Hull contains a considerable amount of silica, together with a portion of a hydrated silicate of iron and magnesia, which causes the ore to yield an olive-brown powder. When the magnetic portion is removed from the pulverized ore by a magnet, there remains a considerable proportion of dull olive-colored earthy matter, which gives a pale brown streak, and is readily attached by hydrochloric acid, with separation of flocculent silica. In the following analysis of an average sample of the ore the whole was treated together, and all of the iron is represented as magnetic oxyd. Neither of the ores from Hull yielded any titanac acid, and the black ore contained neither lime nor manganese. It gave

Magnetic oxyd of iron.....	73.90 = metallic iron 53.20.
Magnesia.....	1.88
Alumina.....	.61
Silica.....	20.27
Water.....	3.27
Phosphorus.....	.027
Sulphur.....	.085
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	100.042

The height of the Hull blast-furnace is 38 feet, its diameter at the boshes being  $10\frac{1}{2}$  feet, and at the throat  $4\frac{1}{2}$  feet; the twyers are six in number. The charge at the time of my visit, in August 1868, consisted of 19 bushels of hard-wood charcoal, 450 pounds of the above ores, previously calcined, and mixed in equal proportions, and 110 pounds of flux consisting of white crystalline limestone 65, clay 27, and silicious sand 18 pounds. The furnace was then yielding gray pig-iron, at the rate of 56 per cent for the ore, while the consumption of charcoal for the ton of metal, was 170 bushels. This was made from beech and maple, and as I was informed by Mr. Kennedy, weighed from 22 to 23 pounds to the bushel, being at the rate of 34 or 35 cwt. of charcoal to the ton of iron.

The furnace was for a time in blast in 1867, and for a longer period,

metallic iron 58.78.

in 1868. By the kindness of Mr. Phillip S. Ross, the secretary to the Canada Iron-Mining and Manufacturing Company, I have been furnished with a statement of the working results during that season.

Working at  
Hull.

The furnace was in blast from April 27 to October 5, 1868, or 163 days, during which time there were consumed as follows:—

Hull ore.....	1835 $\frac{1}{2}$ tons.	} 1896 tons.
Arnprior (McNab) ore.....	60 $\frac{3}{4}$ tons.	
Scrap iron.....		7 $\frac{1}{2}$ "
Limestone (clay and sand not estimated).....		211 "
Charcoal, soft wood at 4 $\frac{1}{2}$ c.....	133,573 bushels.	} 242,782 bushels.
" hard wood at 8c. ....	95,947 "	
" mixed wood at 5 $\frac{1}{2}$ c.....	13,262 "	
Wood at \$1.25.....		25 $\frac{1}{2}$ cords.
Peat, 80 tons, yielding of coke.....		21 $\frac{1}{2}$ tons.
Pig iron produced.....		1040 $\frac{3}{4}$ "

The cost of the iron thus produced was as follows, per ton:—

For ore, fuel, and wages of men.....	\$22.60
Salaries and general expenses.....	3.10
Cost of a ton of pig iron at Hull.....	\$26.50

If we deduct from the total amount of metal produced, the scrap iron added, we obtain, as the average results during the season of 1868, the following figures:—

Daily production of pig iron .....	6 $\frac{1}{2}$ tons.
Yield of ore per ton.....	54.5 per cent.
Charcoal consumed per ton of iron (at 5 $\frac{1}{2}$ cents.).....	235 bushels.
Peat-coke " " " .....	47 pounds.

If we leave entirely out of the account the amount of peat-coke, and take the average weight of the charcoal at 18 pounds to the bushel, we shall have a consumption of 37 $\frac{1}{2}$  cwt. of charcoal to the ton of iron, while, with hard-wood charcoal, there were consumed, as above, from 34 to 35 cwt. In Sweden, according to Bauerman, the average consumption of charcoal, for the whole country, is from 16 to 17 cwt., for the ton of white or mottled pig iron, and about one-third more, or from 21 to 22 cwt., for the ton of gray metal suitable for foundry purposes or for Bessemer steel. At Langshyttta, the consumption is as low as 13 $\frac{1}{2}$  to 14 cwt., for the production of white or mottled iron, while the very poor ores of Taberg, already referred to (page 251), where the charge contains only 20 per cent of iron, require as much as 50 or 60 cwt. of charcoal per ton.

American  
furnaces.

At the Greenwood furnace, near Marquette, on Lake Superior, is a charcoal furnace in which the unroasted ores of the region are smelted with a little crystalline limestone for flux, and yield 55 per cent of iron. To produce a ton of gray pig iron are consumed 140 bushels of charcoal, chiefly of maple, weighing from 16 to 20 pounds each, or about 23 cwt. of charcoal. At the Wyandotte works, near Detroit, where the red slaty hematite of Lake Superior is smelted, and yields on an average 65 per cent of iron, there are consumed 140 bushels of soft-wood charcoal, weighing 14 pounds to the bushel, or  $17\frac{1}{2}$  cwt. to the ton of iron. (Bauerman, *Metallurgy of Iron*, p. 206). The recent returns from American blast-furnaces, published by Prof. Egleston, of the School of Mines, New-York, show that while many American charcoal-furnaces are still working in a very wasteful manner, the consumption of charcoal in some in New York and Michigan, is as low as 100 and 105 bushels. At the large blast-furnaces of Port Henry, on Lake Champlain, where magnetic ores similar to that of Hull are smelted with anthracite coal, the average consumption is from 1.10 to 1.14 tons, equal to 22 or 23 cwt. of anthracite to the ton of pig iron.

With these facts before us, it is clear that the rich ores of Hull, with proper management, should be smelted with 22 or 23 cwt. of charcoal, instead of from 35 to 38 cwt., the quantity actually consumed. This alone is sufficient to explain the failure to produce iron profitably at Hull, where the supply of rich ore is abundant, and the quality of the iron made was excellent.

Hull iron.

It is evident from the analyses of the ores above given that the addition of sand and clay to the charge was unnecessary, and that limestone alone, in proper proportion, would have been sufficient for the purposes of a flux. A series of samples of pig iron made at the Hull furnace, was taken by me for analysis, but the results not being yet complete, are reserved for a future report. It may be stated however that a sample of the white iron made with a mixture of peat-coke and charcoal, contained 0.085 of phosphorus and 0.28 of sulphur. This amount of sulphur may be due to the considerable proportion which, in the form of sulphate of lime, I have found in the ashes of some Canadian peats.

*St. Maurice.*—In the well known blast-furnaces of Messrs. McDougall at St. Maurice, near Three Rivers, in the province of Quebec, where the bog ores of the region are smelted with a hot blast, the charge consists of 500 pounds of ore, with 25 pounds of limestone, and 16 bushels of mixed charcoal. The results for the month of December, 1868, showed a consumption of 26,272 bushels of charcoal and 372 tons of ore, with a yield of  $163\frac{1}{2}$  tons of iron, of which about eleven-twelfths were soft grey pig. This gives a production, for the ore, of 43 per cent of iron, with a

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consumption of 161 bushels of charcoal to the ton. The results of several analyses of the ores of this vicinity, made by me in 1852, are given in the *Geology of Canada*, page 511, and show them to contain more or less manganese, and a considerable proportion of phosphates. The analysis of a specimen of grey pig iron made at St. Maurice, in 1868, gave me the following results for 100 parts.

Iron.....	not determined
Graphite.....	2.820
Carbon, combined.....	1.100
Sulphur.....	.025
Phosphorus.....	.450
Silicon.....	.860
Manganese.....	1.240

St. Maurice,  
Quebec.

The average produce of the St. Maurice forges is about eight tons of iron daily, which is employed for foundry purposes, and is much esteemed for railway wheels. Some four years ago, a small quantity of wrought iron was manufactured from it, in a hearth-refinery, but the quality of the product was somewhat irregular, and the manufacture was abandoned. It is proposed, in a subsequent report, to give the results of farther studies of these and other irons.

*South Crosby.* A large deposit of magnetic iron ore is found on an island in Mud Lake, on the Rideau Canal, in the township of South Crosby, and not far from Newborough. (See *Geology of Canada*, page 674.) Considerable quantities of this ore have been mined, and shipped to Pittsburgh, and to Chicago, for use in puddling-furnaces. This ore, however contains, besides an admixture of chloritic matter, a considerable proportion of titanium, and more or less sulphur in the form of disseminated grains of pyrites. The specimen selected for examination was from a large block sent to the Museum of the Survey, by the Messrs. Chaffey, some years since. Its analysis showed the presence of considerable amounts of alumina, magnesia and water, which belong to the intermingled chloritic mineral. The iron is calculated as magnetic oxyd, although a portion, uncertain in amount, doubtless exists as protoxyd, in combination with the titanitic acid, and with silica, besides that which enters into the composition of the sulphuret of iron present. An average sample yielded as follows;

South Crosby,  
Ontario.

Magnetic oxyd of iron.....	69.77 = metallic iron 50.23.
Titanic acid.....	9.80
Magnesia.....	4.50
Alumina.....	5.65
Silica.....	7.10
Water.....	2.45
Phosphorus.....	.085
Sulphur.....	1.520 = pyrites 2.85.

100.875

An analysis of another portion of this ore, by Dr. A. A. Hayes of Boston, gave 1.49 of sulphur, 5.04 of silica, 4.42 of magnesia, and 16.45 of titanio acid. When the pulverized ore is treated with a magnet, it is partially purified, the non-magnetic portion retaining the sulphur, and a large part of the titanium. The magnetic portion equalled 74.2 per cent, and contained 54.76 per cent of metallic iron and 5.70 of titanio acid.

North Crosby.

*North Crosby.* A specimen of iron ore examined from what is said to be a large deposit on the land of Hon. George W. Allan of Toronto, is a bright crystalline magnetite, free from any visible trace of pyrites, and containing but a small amount of sulphur. Its analysis gave

Magnetic oxyd of iron.....	90.14 = metallic iron 64.90.
Titanic acid.....	1.03
Oxyd of manganese.....	traces.
Alumina.....	1.33
Lime.....	.82
Magnesia.....	.84
Insoluble.....	5.25
Phosphorus.....	.007
Sulphur.....	.120
	<hr/> 99.537

The protoxyd and peroxyd of iron in this ore were separately determined, and found to be exactly in the proportions required by theory for the magnetic oxyd. The insoluble residue was chiefly white quartz, with a little black mica and green pyroxene; it was found in another specimen to equal 10.80 per cent. This is a very fine and valuable ore, and the deposit would seem to be worthy of careful examination.

Belmont.

*Belmont.* The great deposits of iron ore at Belmont have been described in the *Geology of Canada*, page 676 and in the report for 1866, page 100. Since that time, extensive mining operations have there been carried on, and the ore has been shipped to Pittsburg, Pennsylvania. Much of this was found objectionable, on account of the considerable proportion of sulphur which it contained, but an excavation made in the immediate of the former workings, and on what is called the Sand-pit bed, has yielded a much purer ore, to which reference is made in Mr. Vennor's Report in this volume, page 161. I obtained, by crushing several fragments of the ore, taken from a pile at the furnace of Messrs. Shoenberger & Blair, in Pittsburg, Pennsylvania, what seemed an average sample. It was reddish from an admixture of hematite, and yielded

Sand-pit ore.

Magnetic oxyd of iron.....	72.80 = metallic iron 52.41.
Magnesia.....	6.46
Lime.....	.35



Carbonate of lime.....	2.40
" " magnesia.....	.84
Water.....	3.50
Insoluble.....	14.73
Phosphorus.....	.035
Sulphur.....	.027
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	101.142

The analysis of another sample of the Sand-pit ore gave of metallic iron 48.99, water 3.65, carbonate of lime 8.03, carbonate of magnesia 0.48, and insoluble residue 16.52. The carbonates were removed, in both analyses, by acetic acid. The ore contains a considerable admixture of a magnesian silicate decomposable by hydrochloric acid, so that the insoluble residue contains a proportion of soluble silica, which, in the second analysis here given, was equal to 4.25 per cent. The remainder was a silicate of magnesia, iron and a little lime, approaching to pyroxene in composition. The determinations given in this paragraph are by my chemical assistant, Mr. Gordon Broome.

*Madoc.* The Seymour ore-bed in Madoc is described in the *Geology of Madoc, Canada*, page 675, and is further noticed in the Report for 1866, page 98. It was formerly mined and smelted to a small extent, and is a fine grained magnetite, free from pyrites. The analysis gave me

Magnetic oxyd of iron.....	89.22 = metallic iron 64.23.
Insoluble.....	10.42
Phosphorus.....	.012
Sulphur.....	.073
	<hr/>
	99.725

The solution of the ore in hydrochloric acid held neither lime nor manganese. The insoluble residue was decomposed by heating with a mixture of fluorid and sulphate of ammonium, and gave magnesia 17.15, lime 11.01, protoxyd of iron 11.95, silica, by difference, 59.89. This is the composition of actinolite, a mineral which is occasionally found in radiating masses in the midst of the ore.

*McNab.* The hematite of McNab is described in the *Geology of McNab, Canada*, page 677. It has been mined to some extent, and shipped to the United States, and was also used in a small amount at the Hull iron-furnace in 1868, as already described. It is a purplish-red compact or finely crystalline ore, and holds small quantities of silicious matter and of carbonate of lime irregularly disseminated. An analysis by me made in 1847, and cited in the *Geology of Canada*, gave peroxyd of iron 84.10, carbonate of lime 8.80, silica 4.00. A more complete analysis of another specimen has since given me as follows :

McNab

Peroxyd of iron.....	84.42 = metallic iron 59.09.
Carbonate of lime.....	5.40
" " magnesia .....	1.05
Insoluble.....	7.16
Phosphorus.....	.030
Sulphur.....	.065
	<hr/> 99.125

Gros Cap.

*Gros Cap, Lake Superior.* The deposit of hematite which occurs at Gros Cap, on the north side of Michipicoten Harbor, has been described by Mr. Macfarlane in the report for 1866, page 130. A specimen of the ore, selected by him, was submitted to analysis, with the following results.

Peroxyd of iron.....	86.80
Insoluble.....	12.75
Phosphorus.....	traces.
Sulphur.....	.092
	<hr/> 99.642

This ore contained no lime, and the insoluble residue, which was white, appeared to be pure silica.

Bay of Seven Islands.

*Bay of Seven Islands.* On a small stream known as the Rapid River which empties into the Bay of Seven Islands, there occurs, a few hundred yards from its mouth, a great mass of iron ore imbedded in the norite or labradorite rock of the country. The ore, with the exception of an occasional included portion of norite, appeared to occupy the bed and both banks of the stream for a breadth, east and west, estimated at about 500 yards, and is said to extend for some distance north and south, but, owing to a heavy storm at the time of my visit, its limits were not ascertained. The ore is black, brilliant and somewhat coarsely granular. It holds imbedded grains of feldspar, with what appears to be pyroxene, and some iron pyrites. Although pretty strongly magnetic, it contains a large amount of titanium, a partial analysis of an average sample yielding for 100 parts

Titanic iron ore.

Protoxyd of iron.....	49.77 = metallic iron 38.70.
Titanic acid.....	34.30
Insoluble.....	6.35
	<hr/> 90.42

The other bases, derived from the admixture of silicates, were not determined. When pulverized and treated by a magnet it was separated into two portions, one strongly magnetic, equal to 57 per cent. The remainder gave by analysis 51.14 of titanic acid, and 39.75 of peroxyd of iron,

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besides 8.30 of insoluble residue. The magnetic portion, contrary to what might have been expected from the readiness with which it was attracted by the magnet, contained not less than 24.80 per cent of titanitic acid. It was nearly free from silicious impurities, and almost wholly soluble in hydrochloric acid. The existence of a highly magnetic compound, containing so large a proportion of titanium, is interesting, and the substance deserves further study,—meanwhile, as an iron ore, it must take its place with the highly titanitic ores, like that of Bay St. Paul, to which reference has already been made. Should it ever be found advantageous to work such ores, the deposit at the Bay of Seven Islands may be made to furnish a very large quantity.

#### IRON SANDS.

The silicious sands of most regions contain a greater or less proportion of heavy black grains, which consist chiefly of some ore of iron. The source of these is easily traced to the crystalline rocks which, by their disintegration, have given rise to the sands, and which, in addition to occasional beds or masses of iron ores, generally hold disseminated grains of magnetite, hematite, titanitic iron (menaccanite or ilmenite of mineralogists) and more rarely chromic iron ore. In the process of washing earth and sand for gold, diamonds, or tin ore, considerable quantities of these black iron sands are met with, and, from their high specific gravity, remain when the lighter portions are washed away. The chromic iron ore is comparatively rare, and confined to certain districts; the hematite, with the exception of some crystalline varieties, is generally too soft to resist the abrading forces which have reduced the solid rock to sand, so that the black grains, in most districts, consist chiefly of magnetic and titanitic iron ores. In the gold-bearing alluvions of the Chaudière region in Canada, the sands obtained in washing for gold, when purified as much as possible by washing, were found to hold eighteen per cent. of magnetic iron. The non-magnetic portion was soluble in acids and fused bisulphate of potash, with the exception of 4.8 per cent. of silicious residue, and the solutions contained, besides iron, a considerable proportion of chromium, and 23.15 per cent. of titanitic acid, derived from the titanitic iron ore, which made up a large portion of the sand. (*Geology of Canada*, page 520.)

The proportion of these ores to the whole mass of ordinary silicious sands is, generally, by no means large, but the action of moving water effects a concentration of the mixture, separating the lighter silicious grains more or less completely from the heavier portions, which consist chiefly of the iron ores, generally with a small quantity of grains of garnet. This separation is effected, on a large scale, by the action of the sea, under the

*Iron-sand beds.* influence of the winds and tides, and the result of this action occasionally gives rise to remarkable accumulations of these heavy iron sands, along the present sea-beaches. A similar process in past ages, during the deposition of the stratified sands, which are now found at heights above the sea-level, has sometimes arranged the iron grains in layers, which are seen to alternate with the lighter silicious sands, as in the deposits of to-day.

Accumulations of these iron sands are met with in many countries. They are found on the shores of Great Britain, along the borders of the Baltic and the Mediterranean, and abundantly on the coast of New Zealand. In some parts of Hindostan and Madagascar the grains of iron ore are extracted by washing from the sands of the country, and employed by the natives in their primitive furnaces, for the manufacture of iron on a small scale. The iron sands of New Zealand have of late attracted particular attention from their great extent and richness. According to Hochstetter, the shore of the northern island from Kaipara to Taranaki, a distance of 180 miles, is bordered with a thick layer of iron sand, which contains, according to different analyses, from six to eleven per cent. of titaniferous acid.

*New Zealand.* In North America, black iron sands abound in many places. They occur in great quantities in the lower St. Lawrence, as will be hereafter described, and are met with, in smaller amounts, at various points to the south-westward, along the valley of the St. Lawrence and the great lakes. Thus, a deposit of black sand at the outlet of Lake Huron, near Sarnia, attracted some attention, a few years ago; while along the north shore of Lake Erie this sand is, in some places, found in such quantity that attempts were, it is said, made, more than twenty-five years since, to collect it and smelt it with an admixture of bog ore, which was then treated in a blast-furnace, at Normandale, Norfolk county, Ontario.

*Western lakes.* These black sands are likewise met with at various points along the coast of the United States, particularly on the shores of Connecticut, where they early attracted the attention of the colonists, and were successfully worked more than a century since. The following details relating to the history of these early and little-known trials, are so interesting that I may be pardoned for introducing them here. It appears by a letter from Mr. Horne, a steel-maker and cutler of London, addressed to Mr. John Ellicot, F.R.S., and read before the Royal Society of London, March 3, 1763, that, at that time, the Society for the Encouragement of Arts and Manufactures was occupied with the question of the Virginian black sand, as it was called. Already, before 1742, one Dr. Moulton, of the Royal Society, had made some unsuccessful experiments to determine the nature of this magnetic sand, but in that year Mr. Horne, having procured a quantity of it, succeeded, as he tells us, in extracting from it more than one-half of its weight of fine malleable iron. He seems, however, to have pub-

*Early workings.*

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lished nothing upon the subject until after Mr. Jared Elliot had made known, twenty years later, by a pamphlet and a letter addressed to the Society of Arts, and subsequently by a letter in reply to Mr. Horne's inquiries, <sup>Elliot's trials.</sup> that he was then making malleable iron from the black sands, in blooms of fifty pounds and upwards, by direct treatment in a common bloomary fire, a process which seems, from his letters, to have been one familiar to him. He describes the ore as yielding 60 per cent. of malleable iron, and as being very abundant, and so free from impurity as to require the addition of cinder or of bog ore. This manufacture of iron from the sand had evidently been somewhat developed, for, according to Mr. Elliot, his son had already erected a steel-furnace, before the Act of Parliament was passed prohibiting the manufacture of steel in the colonies. Specimens of the steel there produced were examined by Mr. Horne, and found to be of excellent quality, very tough, and not at all red-short.\*

Throughout the essay of Mr. Horne the sand-ore is spoken of as coming from Virginia, a name which in the reign of Elizabeth was given to the whole American coast from Canada to Florida, although in 1643 the name of New England was applied to the region which still bears that name. It appears, however, that the so-called Virginia sand was from the coast of Connecticut. Mr. Elliot's letter to Mr. Henry Horne was dated Kill- <sup>Connecticut,</sup> ingworth, Oct. 4, 1762. Killingworth is a town in the state of Connecticut, on the shore of Long Island Sound, twenty-five miles east of New Haven, and was the residence of the Rev. Jared Elliot, D.D., who was not only a divine, but a physician, and a naturalist of great reput. It is recorded of him that "some considerations had led him to believe that the black sand, which appears originally on the beach of the sound, might be wrought into iron. He made an experiment upon it in the year 1761, and succeeded. For this discovery he was honored with a medal by the society instituted in London for the Encouragement of Arts, Manufacturers and Commerce." \*

Notwithstanding this successful result, the iron sands seem to have been neglected for the last century, both in America and in Europe. We read, it is true, that such sands are treated in open hearths (bloomaries) at Avellino, near Naples, and within a few years attempts have been made in England to turn to use the iron sands of New Zealand; but the first successful attempts in this country were on the north shore of the lower

\* These curious details are extracted from a rare volume entitled *Essays concerning Iron and Steel*, (the first of the three essays being on "The American Sand-Iron," by Henry Horne, London, 1773. 12mo., pp. 223. A copy of this scarce book is in the possession of W. M. B. Hartley, Esq., of New York.

\* Barber's *Historical Collections of Connecticut*, page 531. The Rev. Jared Elliot, who was a grandson of the celebrated John Elliot of Massachusetts the "Apostle of the Indians," died in 1763, aged seventy-eight years.

St. Lawrence. The great deposits of black iron sand on the beach near the mouth of the Moisie River, having attracted attention, various attempts to reduce it were made. In January, 1867, Mr. W. M. Molson of Montreal, had the ore successfully treated by the bloomery process, in northern New York, and the result proving satisfactory, several bloomery furnaces were, in 1867, constructed by him at Moisie, and have since been in successful operation.

Moisie.

It will here be well to notice the nature and the composition of the iron sand at Moisie, as observed by myself in the summer of 1868. The stratified sands at Moisie, lying about ten feet above high-water mark, penetrated by the roots of small shrubs, and holding marine shells, were observed to be banded by irregular dark colored layers, in which the iron ore predominated. The same thing was afterwards remarked by me in stratified sands at much higher levels in the vicinity. Where these sands form the beach, they are exposed to the action of the waves, which effect a process of concentration, on a grand scale, so that, it is said, after a prevalence of certain winds, great belts of nearly pure black sand are exposed along the shore. At the time of my visit trenches were being sunk to a depth of five feet, on the shelving beach, about half-way between high and low-water mark. The sections presented alternations of nearly pure silicious sand and of black iron sand, the latter in layers of from half an inch to six inches in thickness, often with a small admixture of grains of red garnet, which sometimes formed very thin coatings upon the surface of the black layers. One of these latter, six inches in thickness, was taken up by myself, and found to be very pure, as will be seen from its analysis, farther on. It was easy, from these trenches, by means of shovels, to remove, without much admixture, the thicker layers of the moist black sand, which would measure from one and a-half to two feet out of the five feet excavated. This material was piled upon the beach, and afterwards carried to the washing-table. The supplies of sand-ore have hitherto been obtained from the deposits of wet sand below high-water level. Those at the surface, on the beach, have doubtless been recently moved by the waves, but from the inspection of the layers in the trenches, I was led to the opinion that they were lower strata, similar to those seen above the high-water mark, and, like them, of considerable antiquity. They were found to contain marine shells in a crumbling and decayed condition. It is said that these mixed sands of the higher levels yield, on an average, by washing, about fifteen per cent. of black iron sand. When this poor sand is spread upon the shore, and exposed to the action of the waves and the tide, it is found to become concentrated through the washing-away of the silicious grains. This process helps us to understand the mode in which the irregular layers of rich iron sand have been formed in the



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The washing of the ore at Moisie, preparatory to smelting, is done upon a shaking-table, about twenty feet long and four feet wide, with a sloping and somewhat concave bottom. Upon this, by the aid of a gentle current of water, a large part of the lighter grains, chiefly of quartz, are washed away.

Washing the sand.

The specific gravity of the sand, in bulk, was determined by weighing 100 measured cubic centimeters of it, equivalent to 100 grammes of water; and the proportion of grains of magnetic ore was also determined. Of three specimens from Moisie; A was an average sample of several hundred tons gathered in the manner just described, preparatory to washing; B, a portion taken by myself from a layer six inches thick, about three feet below the surface of the beach; and C, the washed ore, as prepared for the bloomy fire. In this connection are given the results of some similar determinations with iron sands from other localities.

	<i>Specific gravity.</i>	<i>Magnetic.</i>
Moisie, A.....	2.82	46.3 per cent.
Moisie, B.....	2.83	49.3
Moisie, C.....	2.97	52.0
Mingan.....	2.84	48.3
Bersimis.....	2.81	34.3
Natasquan.....	—	53.7
Kagashka.....	—	24.0
Batiscan.....	—	55.0

The specific gravity of the silicious sand with which these iron sands are associated, was found, when determined in bulk, as above, to be about 2.00. It consists chiefly of quartz, whose real specific gravity is about 2.65; that of magnetic iron ore being about 5.18, while the titanite iron ore is about 4.70, and the associated garnet not far from 4.0. The amount of material removed in the process of washing at Moisie is not very great, as may be seen by comparing the proportion of magnetic grains in A and C, the Moisie sand before and after washing. The latter was found by analysis to contain about 5.5 p. c. of insoluble matter, chiefly silicious sand, the remainder being almost entirely oxyd of iron and titanite acid.

The sand of Batiscan, mentioned above, had been purified by washing. Considerable deposits near Champlain, contain, according to Dr. Larue, about 10.0 per cent. of magnetic ore, the remainder being chiefly silicious sand. The specimens from Bersimis, Mingan, Natasquan and Kagashka, however, though collected, as I was informed, without washing, compare favorably with those from Moisie, and, with the exception of Bersimis, even

Bersimis.

surpass it in the proportion of magnetic ore. I am indebted for all of these to Dr. Larue, the professor of chemistry in Laval University, Quebec, who has paid much attention to the iron sands of the lower St. Lawrence, and collected himself the specimen from Bersimis, of which locality he has given me some interesting notes. Besides the considerable accumulations of sand on the beach, he observed, about three feet above high-water mark, two layers of black sand, holding about 30 per cent. of magnetic ore, and separated by a stratum of four inches of a gray sand containing very little iron. The three layers were traced with considerable regularity for 1000 feet along the shore. As we have seen, the sand from the beach at Bersimis contained but 34.3 per cent. of magnetic ore, and had a specific gravity of 2.81; the magnetic portion had, however, a specific gravity of 2.99, and the non-magnetic 2.77. The analyses of both of these will be found farther on.

Bay of Seven Islands.

Mingan.

A deposit of black sand, said to be equal in richness to that of Moisie, is described as stretching along the coast, nearly the whole distance from the Bay of Seven Islands to the mouth of the Moisie River. The sand from Mingan, which is mentioned above, and of which an analysis will be given farther on, is said to be from the west side of the St. John River, at leagues along the coast, and as being very abundant. The deposits of sand at Natasquan and at Kagashka are also stated to be very extensive, and like Mingan, favorably situated for the loading of vessels.

Magnetic separation.

An inspection of the iron sands from the various localities above mentioned, shows that they all contain, besides the ores of iron, a small proportion of red garnet, and more or less of fine silicious sand. The latter of the two substances it is possible to remove almost entirely by careful washing of the crude ore. The use of a magnet enables us to separate the black iron ore grains into a magnetic portion, which is nearly pure magnetic oxyd, and a non-magnetic portion, which is chiefly titanitic iron, but, in the specimens submitted to examination, holds a portion of silicious matter, which the imperfectly washed sand still retains. In thus separating the ores into two portions for analysis, the magnetic grains were taken up by a magnet, the poles of which were covered by thin paper, and this process was repeated until the non-magnetic grains were, as far as possible, left behind. The two portions of the ore thus obtained were analyzed separately, the solvent used being, in both cases, hydrochloric acid, which, as is well known, dissolves magnetic oxyd of iron with great facility, and, with certain precautions, may be advantageously employed to dissolve titanitic iron ore. For this purpose the non-magnetic portion, having been very finely powdered and sifted, is left to digest with about ten times its weight of hydrochloric acid of specific gravity 1.19, or thereabouts, for

several hours, or until the undissolved residue is no longer black, but grayish or brownish in color. If the process has been conducted with care, and without over-heating, the whole of the iron, and all of the titanitic acid which was combined with it, will be found in solution, and may be separated by the ordinary methods. The residue, apparently, contains little else than grains of quartz, with a small proportion of garnet. The finely pulverized ore may also be fused with bisulphate of soda, a process which is more expeditious, and yields equally good results with the last.

*Moisie*.—A specimen of unwashed black sand from Moisie, holding 49.1 per cent of magnetic grains, was decomposed by digestion with hydrochloric acid, and the residue fused with bisulphate of soda. The titanitic acid having been thrown down, by boiling, from the united solutions, the iron was directly determined, the other bases being neglected in this partial analysis, which gave me the following results :

## I.

Protoxyd of iron.....	70.10 = metallic iron 55.23
Titanic acid.....	16.00
Insoluble, chiefly quartz .....	5.92
	<hr/>
	92.02

A part of the iron in these ores is in a higher state of oxydation than here indicated, but the determination of the degree of oxydation of the iron in titanitic ores is difficult, and, as even the magnetic portion of the sands contains some titanitic acid, it is thought advisable, in the present analyses, to represent the whole of the iron in these ores as protoxyd, giving, at the same time, the amount of metallic iron, and, in the case of the magnetic portions, the magnetic oxyd corresponding thereto. In the non-magnetic portion of the Bersimis sand, however, as will be seen, the proportions of the two oxyds of iron were determined. The magnetic grains having been removed from the above sample of Moisie ore, the non-magnetic portion gave 58.20 of protoxyd of iron, 30.74 of titanitic acid, and 6.14 of insoluble residuum.

Further and more complete analyses were subsequently made of the washed ore from the Moisie iron-works, which, as already stated, contained 52.0 per cent. of magnetic grains. These were analyzed separately, (II) while the non-magnetic portion gave me the results under III. Sulphur and phosphorus are present in this sand in very small quantities, the determinations of Mr. Broome giving for the washed mixed ore .070 per cent. of sulphur and .007 of phosphorus.

Chemical  
analysis.

Moisie sand.

Moist sand.

	II.	III.	I A.
Protoxyd of iron .....	85.79	56.38	71.08
Titanic acid.....	4.15	28.95	16.55
Oxyd of manganese.....	.40	1.10	....
Lime.....	.90	.95	....
Insoluble .....	1.95	8.75	5.35
	<hr/> 93.19	<hr/> 96.13	<hr/> ....
Magnetic oxyd of iron.....	92.68	....	....
Metallic iron.....	66.73	43.85	55.27

The sum of the analysis II, if the iron be calculated as magnetic oxyd, is 100.08. The composition of the mixed ore, if we suppose II and III to be mixed in equal proportions, would be as under I A, which agrees closely with the analysis I, given above.

*Bersimis.*—The iron sand of Bersimis, as already described, contained but 34.7 per cent of magnetic grains; the analysis of this portion is given under IV.

	IV.
Protoxyd of iron.....	85.56
Titanic acid.....	3.40
Oxyd of manganese. ....	undet.
Lime .....	traces.
Magnesia .....	...
Insoluble .....	3.85
	<hr/> 92.81
Magnetic oxyd of iron.....	92.44
Metallic iron .....	66.56

The sum of the analysis, if the iron be calculated as magnetic oxyd, is 99.67. The non-magnetic portion of the Bersimis sand was dissolved in hydrochloric acid, out of contact with oxygen, and the amounts of protoxyd and peroxyd of iron were separately determined. The analysis gave me as follows:—

	V.
Protoxyd of iron.....	24.66
Peroxyd of iron .....	22.24
Titanic acid.....	26.95
Oxyd of manganese .....	1.10
Lime .....	1.12
Magnesia .....	.72
Insoluble .....	23.80
	<hr/> 100.59
Metallic iron .....	34.94

*Mingan.*—The iron sand from the mouth of the St. John river, at Mingan, contained 48.3 per cent. of magnetic grains, whose analysis is given under VI, while that of the non-magnetic portion of the ore is found under VII. Mingan sand.

	VI.	VII.
Protoxyd of iron.....	80.46	46.31
Titanic acid .....	6.50	31.60
Oxyd of manganese .....	.52	1.35
Lime .....	.75	1.06
Magnesia.....	.70	.50
Insoluble.....	4.20	15.50
	<hr/> 93.13	<hr/> 96.32
Magnetic oxyd of iron .....	86.92	....
Metallic iron.....	65.58	36.00

The sum of the analysis VI, if the iron be estimated as magnetic oxyd, is 99.59.

In the above analyses of the iron sands it will be remarked that the magnetic portion retains a little adherent silicious matter, and small amounts of titanium, both of which vary in the sands from different localities, although the separation by means of the magnet was in all cases effected with the same precautions. Observations and experiments on other samples of these sands go to show that different layers from the same locality vary, not only in the proportion of silicious sand, but in the relative proportions of magnetic and titanic ores and of garnet. This might be expected when we consider that the differences in density between each of these constituents of the sand, should, under the influence of moving water, lead to their partial separation from each other.

Varying composition.

A specimen of iron sand from Quogue, on the south side of Long Island, near New York, where these sands are about to be employed for the manufacture of steel, closely resembled those of Bersimis, and contained 31 per cent. of magnetic grains. The unpurified ore, which was mingled with a considerable amount of quartz sand, and some garnet, amounting together to about 17 per cent., gave by analysis about 40 per cent. of iron, and 15 per cent. of titanium, besides a proportion of manganese greater than the iron sands from the lower St. Lawrence.

#### ON THE MANUFACTURE OF IRON AND STEEL BY DIRECT METHODS.

Although by far the greater part of the wrought iron and steel now used in the arts is made from cast iron produced in the blast-furnace,

Iron by direct  
processes.

Furnaces.

Catalan forge.

the history of iron-making shows us that in early times malleable iron, and even steel, were obtained directly from certain ores, without the previous production of cast iron, and without fusion. The manufacture and use of the latter, in fact, date only from a comparatively recent period. The natives of India, Burmah, Borneo, Madagascar, and some parts of Africa, practice the direct conversion of iron ores to the metallic state in small furnaces. In certain districts of India the amount of malleable iron thus produced is very considerable, and much of it is manufactured into steel; but the furnaces used are small in size, and produce not more than from twenty to forty pounds of iron in a day, with the labor of three or four men, and with a great waste of ore and of charcoal. The rich native ores, coarsely pulverized, or the grains of iron ore obtained by washing the sands of certain districts, are heated with charcoal in small furnaces, until they are reduced and yield masses of malleable metal. Somewhat similar methods of making malleable iron have long been known in various countries of Europe, where, under improved forms, they are still followed, and have thence been brought to America. Of these furnaces for the direct conversion of ores into malleable iron, the five known in Europe are the Corsican and Catalan forges, the German bloomary forge, the Osmund furnace, and the German Stückofen or high-bloomary furnace, which latter had high walls, and approached in form to the modern blast-furnace, of which it seems to have been the immediate precursor. For a detailed description of these various furnaces, and the mode of working them, the reader is referred to Dr. Percy's learned work on the metallurgy of iron and steel. Inasmuch, however, as furnaces related to the German bloomary are still largely used on this continent, and promise to become of considerable importance to Canada, it will be well to describe briefly some points in the history of these various European furnaces.

Of these, the best known is the Catalan furnace or forge, so called from the province of Catalonia, in Spain, where it was formerly much used, as well as in the neighboring parts of France. The department of Ariège, in 1840, had in operation forty-nine of these furnaces, producing 5800 tons of metal, of which 215 tons were a crude kind of steel, the remainder being malleable iron. The process has there, however, since probably fallen into disuse. Similar forges continue to be employed on the Italian coast, and, in 1850, there were forty of them in operation in the province of Genoa, where they were used for the treatment of specular iron ore brought from the island of Elba. In the French Pyrenees, however, (department of Ariège) the ore generally used in these furnaces is a hydrous brown oxyd, holding from forty to fifty per cent. of iron, and approaching in its character to the bog ores of the province of Quebec.

The Catalan forge consists of a rectangular hearth, constructed chiefly



malleable iron, and without the previous manufacture and use of recent period. The some parts of Africa, in the metallic state in small malleable iron thus manufactured into steel; not more than from one of three or four of the rich native ores, and by washing the small furnaces, until Somewhat similar in various countries still followed, and the direct method in Europe are the Osmund furnace, which latter is a blast-furnace, of For a detailed working them, the metallurgy of iron is a very common bloomery some of considerable importance in some points

large, so called, and very much used, in the department of Ariège, producing 5800 tons of iron, the remainder of the province probably from the Italian province of the province of iron ore, but, however, the furnaces is a very common bloomery of iron, and of Quebec. It is chiefly

of heavy iron plates, which, in the largest size, is about forty by thirty-two inches, and from twenty-four to twenty-seven inches deep, or from fourteen to fifteen inches below the twyer. In some districts, however, furnaces of not more than one-half these dimensions are built. The pressure of the blast employed does not exceed  $1\frac{1}{2}$  or  $1\frac{3}{4}$  inches of mercury, and the twyer is directed downwards, at an angle of thirty or forty degrees. The wall facing the twyer, slopes outward towards the top, and in working, the greater part of the charge of ore is heaped against it, and occupies from one-third to one-half of the cavity of the furnace, the remaining space being filled with ignited charcoal. The ore is previously broken so that the large lumps are not more than two inches in diameter, while from one-third to one-half of the material will pass through a screen, the bars of which are four-tenths of an inch apart. This finer ore is thrown on the surface of the fire, from time to time, during the operation, which is conducted with many precautions as to regulating the blast, stirring, supplying the fine ore and coal. At the end of six hours, in the ordinary routine, there is withdrawn from the bottom of the furnace an agglomerated mass of reduced but unmelted iron, which is then forged into blooms or bars. The operation, lasting six hours, consumes, in one of the larger sized forges, about  $9\frac{1}{2}$  cwt. of ore and  $10\frac{1}{2}$  cwt. of charcoal, and yields 3 cwt. of bar iron. According to another calculation, there are required for the production of 100 pounds of iron, 340 pounds of charcoal and 312 pounds of an ore containing from 45 to 48 per cent. of iron. Of this about seven-tenths are obtained in the metallic state, the remaining three-tenths passing into the slag. 100 pounds of ore yield 31 pounds of bar iron, and 41 pounds of slags, which are dark-colored basic silicates, very rich in oxyd of iron.

Mode of working.

The Corsican forge is a more primitive form of furnace than the Catalan, and without interest, except so far as it belongs to the history of iron-working. It is said to have consumed more than 800 pounds of charcoal for the production of 100 pounds of iron. Some few of these forges were still in operation in Corsica forty years since.

Corsican forge.

Another form of furnace, described by Dr. Percy under the name of the Osmund furnace, was used during the last century in Norway and Sweden. It was a rude hearth, with walls around it, and an opening in one of the side near the tap-hole, which was built up with stones, and taken down when it was required to extract the lump or mass of reduced iron. This furnace was not capable of yielding more than  $1\frac{1}{2}$  tons of iron in a week, but is still used in Finland, and it is mentioned as a curious fact, that certain bog ores which contain so much phosphorus as to yield but a poor and hot-short iron by treatment in the blast-furnace, and subsequent decarburization, afford a good malleable iron when reduced by the direct method,

Osmund furnace.

in the Osmund furnace; a result which appears to be due to the fact that the phosphorus, which is reduced and passes into the iron, in the blast-furnace, escapes reduction at the lower temperature of the Osmund furnace.

Improved Catalan, or Genevieve forge.

An improvement in the Catalan forge has been introduced in the province of Genoa, in northern Italy, and consists in the utilization of the waste heat, which is made to roast, and subsequently partially to reduce, the ore before treating it in the forge. For this purpose a flat-bedded reverberatory furnace, so constructed as to receive, at one end, the flame from the forge, was provided at the other end with a charging-door, within and above which was a vertical chamber, communicating with the chimney, and having a side-door, and a grating at the bottom. Upon this grating, the ore, a specular oxyd containing 68 per cent of iron, was laid, and exposed to the heat, which roasted it, expelling a small portion of sulphur. After being thus heated for some time, it was withdrawn and thrown into water, by which process it was rendered friable. Being then broken into small lumps and coarse powder, it was spread out evenly on a layer of broken charcoal, with which the bottom of the reverberatory hearth had previously been covered, and was here exposed to the heating effect of the waste flame from the forge, during the whole time of working a charge in the latter. In this operation the bed of charcoal was consumed, and the ore lost ten or twelve per cent. of its weight, being partially deoxygenized. Some scraps of cast iron or wrought iron were then added to the half-reduced ore, and the whole mass, by means of a rabble introduced through the charging-door, was pushed forward into the forge-hearth. In this way, five heats, instead of four, could be worked off in twenty-four hours, with great economy in charcoal, improvement in the quality of iron, and a somewhat greater yield. Separate furnaces were also constructed in connection with these works, for reheating the iron to be drawn out into blooms, and the waste heat from these was also employed in heating reverberatories, as above explained.

Working results

One of the Catalan forges, with these improvements, yields in a week of six days, thirty heats of iron, with an average consumption, for each heat, of 95.30 kilogrammes of ore in lumps, 68.50 of ore in powder, 31.75 of wrought-iron scrap, and 254.00 of charcoal, with a yield of 143.00 kilogrammes of bar iron. This is equal to 1575 pounds of iron in twenty-four hours, with a consumption of 2794 pounds of charcoal. It is, however, to be noticed that about 22 per cent. of this product, or 349 pounds, was added in the condition of wrought-iron scrap, whose reworking would consume comparatively little charcoal. Making a liberal allowance for this, we may fairly consider the work of the furnace as nearly equal to the production, from the ore, of 1400 pounds of iron, which is at the rate of 50

due to the fact that the iron, in the blast, is of the Osmund

duced in the province of the waste heat. To reduce, the ore before added reverberatory from the forge, within and above chimney, and having regrating, the ore, and exposed to the hur. After being wn into water, by n into small lumps of broken charcoal, l previously been f the waste flame rge in the latter. d the ore lost ten ed. Some scraps half-reduced ore, gh the charging-way, five heats, urs, with great and a somewhat d in connection nto blooms, and erberatories, as

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pounds of iron for 100 pounds of charcoal consumed, and is about the result obtained with the American bloomaries, to be noticed farther on; while the proportion obtained with the unimproved Catalan forge, described above, is only at the rate of 30 pounds of iron to 100 pounds of charcoal.

Mention has already been made of the German high-bloomary furnace, or Stückofen, which is of no particular interest in this connection, and is not to be confounded with another furnace known simply as the German bloomary. This was formerly used in Silesia and the Palatinate, and is described at some length in the classic work of Karsten, written a little more than half a century since (1816), but is dismissed with a few words in Bruno Kerl's treatise on metallurgy, published in 1864 (*Huttenkunde*, iii, 427), from which its use would seem to be nearly or quite abandoned in Germany. According to Karsten the German bloomary consisted of an iron pot, or a box of iron plates, in either case lined with refractory bricks, and having an internal diameter of from fourteen to twenty-one inches, and the same depth, the dimensions varying with the fusibility of the ore, the force of the blast and the quality of the coal. The twyer was horizontal; the furnace having been filled and heaped up with burning charcoal, the ore was thrown upon the fire by shovels-full at a time; this process was continued, the supply of fuel being renewed, until a loup of sufficient size had been formed at the bottom of the hearth, as already described in the Catalan method. When the blast is too intense, or the coal very dense, it may happen that the reduced iron becomes carburetted to such an extent as to produce steel-like iron, or even molten cast-iron, instead of a loup of soft malleable iron. A similar state of things sometimes occurs in the Catalan forge, and is occasionally taken advantage of to obtain an imperfect kind of steel.

German bloomary.

From the above description it will be seen that the method by the German bloomary differs from that by the Catalan forge, in the fact that, in the latter, the greater part of the charge of ore is placed, at the commencement of the operation, in a coarsely broken state, on the sloping wall of the furnace, opposite to the twyer, while the remaining portion is subsequently projected, in a more finely divided condition, upon the surface of the fire. In the German method, on the contrary, the whole of the ore is reduced to this finer condition, and is added by small portions, a plan which dispenses with the charging of the furnace after each operation, as in the Catalan method, and permits of a continuous working, interrupted only by the withdrawing of the lous from time to time. The German bloomary, in an improved form, is extensively used for the reduction of iron ores in the United States, where it is known by the name of the bloomary fire, the Jersey forge, or the Champlain forge, and is also frequently called

Distinguished from Catalan.

the Catalan forge, from which, as has already been shewn, it is distinct in form, and still more distinct in the manner in which it is worked. Before proceeding to describe in detail the American bloomary fire, it will be well to notice some of the advantages of the direct methods of extracting iron from its ores, and to point out the conditions under which they may be used with advantage.

Karsten remarks that the iron obtained by a direct process is often of a superior quality, for the reason that the separation of the foreign matters of the ore is effected by a kind of liquation, rather than by complete fusion; and, moreover, that certain impurities, which would be reduced and unite with the iron at higher temperatures, are carried off by the slags, in an unreduced state, at the lower heat of the open forge. A striking illustration of that has been given above, in speaking of the Osmund furnace, and its use in Finland. For these reasons Karsten was of the opinion that in some regions, and with certain ores, the direct process was, perhaps, more advantageous than the use of the blast-furnace combined with the finery-hearth. This, however, was half a century since, and, in the meantime, great improvements have been made in the manufacture of cast iron, as well as in puddling or otherwise treating the pig-metal. In view of all these facts, and of the great facilities for transportation at the present day, Dr. Percy observes (in 1864), "that there can only be comparatively few localities in Europe where these (Catalan) forges can be conducted with profit. In mountainous regions abounding in rich iron ores and wood suitable for charcoal, and still inaccessible to railways, the Catalan process may hold its ground, but certainly not in localities where it is unprotected by high rates of carriage, or other circumstances, from competition with iron smelted and manufactured by modern processes. Its advantages are that the outlay and floating capital required for a forge are inconsiderable, and the consumption of charcoal is comparatively small."—(Percy, *Metallurgy of Iron and Steel*, page 311.)

The German bloomary process was probably introduced into North America early in the last century. Among the forges in operation in New Jersey and Pennsylvania in 1856, Lesley, in his *Iron Manufacturers' Guide*, mentions one as having been established in 1733, and another in 1725. These were, perhaps, bloomaries for the conversion of pig-iron by the Walloon method, which was used in this region at an early date; but it is evident, from facts cited already, page 263, that the treatment of pulverized iron ores in the German bloomary fire was already practised in Connecticut as early as 1761. It was, probably, the coming of German immigrants which led to the use of the German rather than the Catalan forge, which, so far as I can learn, is unknown, at least, in the northern and eastern parts of the United States. Various improvements have

Bloomaries in  
America.

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been, from time to time, made in the construction of the furnaces, the most important of which has been the introduction of the hot blast. Favored by supplies of rich ores, and protected, to a certain extent, from foreign competition, by duties on imported iron, the manufacture of iron by this method has been widely extended over the United States, and has assumed considerable importance. In the districts where it was first introduced, including northern New Jersey and the adjacent portions of New York and Pennsylvania, the bloomary process is falling into disuse, since wood has become scarce, and extensive workings of coal in the vicinity, with the great facilities for transportation, have rendered it more profitable to treat the ores in the blast-furnace than in the bloomary fire. In northern New York, on the contrary, the use of the direct process appears to have considerably extended during the past few years.

The works for producing iron directly from the ores, by the present method, are known in the United States as forges or bloomaries, and sometimes consist of twenty forge-fires or furnaces, but in many cases of not more than two or three. According to the report prepared by Mr. Charles E. Smith, for the *Iron Manufacturer's Guide* (page 760), and published by authority of the American Iron Association, there were, in the year 1856, produced directly from the ore, 28,633 tons of malleable iron, from 203 forge-fires. Of these, 42 were in New York, 48 in New Jersey, 36 in North Carolina, 14 in Alabama, and 50 in Tennessee. There were besides, at that time, 35 abandoned fires, of which not less than 29 were in New Jersey. The average production from each forge-fire was thus 141 tons. Since that time I have no means of knowing the condition of this manufacture in the south and west. In New Jersey, for reasons already given, the direct method is almost abandoned, while in northern New York, on the contrary, it has greatly increased. Instead of the 42 fires reported in 1856, there were, in 1867, according to the Iron and Steel Association Bulletin, 136 fires in activity in Essex and Clinton counties, the principal seats of this industry. The aggregate product of these forges was supposed by a competent authority, in 1868, to be nearly 40,000 tons of malleable iron, a large portion of which is consumed at Pittsburg for the manufacture of steel by cementation, a process for which this iron is eminently fitted, and for which that reduced from the ore of the Palmer ore-bed, near Keeseville, is especially prized. Two establishments in the neighborhood work the ore of this deposit ; one, that of Messrs. Rogers, of Ausable Forks, had 21 fires, and the other, that of the Peru Company, of Clintonville, 18 fires, in 1868.

The direct method of reduction cannot be applied to poor ores, which, to yield good results in the German or Catalan forge, should not contain much less than 50 per cent. of iron, while much richer ores are to be pre-

Bloomaries in  
United States.

New York  
forges.

Palmer ore-bed.

ferred. Some of the iron ores of North America consist of an aggregate of crystalline grains of magnetic oxyd, mingled with so large a proportion of calcareous or silicious matter as render them unfit for the bloomary fire, without purification. This is generally effected by crushing and washing, after a previous partial calcination, and leaves the ore in a coarsely granular state, which would not be adapted to the Catalan, although well suited to the German or American method. This condition of things is illustrated by the ore of the famous Palmer bed, just mentioned. I was informed at the works of Messrs. Rogers, that from four to five tons of the average crude ore were required to make a ton of blooms. The ore, as raised from the mine, is chiefly magnetite, with grains of white quartz, and, in some portions, of flesh-red feldspar. It is slightly roasted, to render it friable, then stamped and passed through screens with openings of about one eighth of an inch, and purified by washing. Two tons of the washed ore were required to make a ton of blooms. I took what seemed an average sample of the crushed ore from the stamps, and having further reduced it so that it would pass through the meshes of a sieve having sixteen holes to the linear inch, carefully separated the magnetic from the non-magnetic part, which contained a proportion of grains of specular iron ore, but was chiefly quartz. The magnetic portion equalled 45 per cent. of the whole. A sample of the dressed ore, such as supplied to the bloomaries, was treated in the same manner, by further crushing, and separation by the magnet, and contained 64 per cent. of magnetic ore; the non-magnetic portion, besides silicious matters, holding a considerable proportion of grains of specular iron, which would probably raise the amount of oxyd of iron in this sample of the water-dressed ore to about 85 per cent., or a little over 60 per cent. of metallic iron. In other districts of northern New York, as in the vicinity of Port Henry, the crude ores are richer than those just mentioned, and often contain very little extraneous matter, so that the operation of washing may sometimes be dispensed with. At the New Russia forge, in Moriah, the ore, which is mingled with a little quartz, is roasted in piles, with wood, during two or three days, then crushed and treated as above described. Two tons of the crude ore yield one and a half of dressed ore, which is calculated to give one ton of blooms. The washing process removes not only the foreign matters, but a portion of fine ore, which is lost, and may be seen accumulated in the vicinity of the washing-tables. The bloomers, as the iron-makers are called, object to this fine ore, as being unfit for use, but it will be seen further on that this prejudice is without foundation, and that the finer grains can be used with advantage, though they are now rejected, and considerable loss is thereby incurred.

The magnetic ores of Lake Champlain are exported to Vermont, where, for several years, a few bloomaries have been supplied with iron ore from

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the west side of the lake. Three forge-fires were, in 1868, in operation at Salisbury, and three at East Middlebury, Vermont, five miles from the Middlebury station on the Rutland and Burlington Railway. The ore for this purpose is brought by water from Port Henry or Port Kent to Burlington, and thence by rail to Middlebury station. This is brought partly in lumps, which are crushed and washed at the forge, and partly dressed to a high degree of purity, and ready for use.

Overman is, so far as I am aware, the only writer who has given any account of the American bloomary process. In his *Treatise on Metallurgy* (sixth edition, 1868, page 541), will be found a description, accompanied by figures. My own observation, as here given, have enabled me to verify the general correctness and trustworthiness of Overman's statements with regard to this subject.

The bloomary hearths or furnaces in different localities exhibit some little variations in size and in the details of their arrangements. The size of the hearth varies from twenty-seven by thirty to twenty-eight by thirty-two inches, and the height, from twenty to twenty-five inches above the twyer, and from eight to fourteen inches below. The sides are made of heavy cast-iron plate, and the bottom, although often of beaten earth or cinders, is, in the best constructed hearths, also of iron, made hollow, and kept cool by a current of water, which is made to circulate through it. In the East Middlebury forges this bottom-plate is four inches thick, and has within it a hollow space of two inches. The side-plates, which slope gently inwards, in descending, and rest on ledges on the bottom-plate, are one and a-quarter inches thick. A water-box, measuring twelve by eight inches, is let into the twyer-plate, and a stream of cold water circulates through this box, and through the bottom-plate, as well as around the twyer. The length of the hearth, from the twyer-plate to that opposite, is twenty-four and a half inches, and the breadth from front to rear is twenty-nine inches. The twyer enters twelve inches above the bottom, and is inclined downwards at such an angle that the blast would strike the middle of the hearth. The opening of the twyer has the form of the segment of a circle, and is one inch high by one and three-quarter inches wide. In front of the furnace, at sixteen inches from the bottom, is placed a flat iron hearth, eighteen inches wide. The side-plate beneath it is provided with a tap-hole, through which the melted slag or cinder may be drawn off, from time to time. The iron plates used in the construction of these furnaces last for two years. In the furnaces used at the New-Russia works in Moriah, already mentioned, the iron bottom-plate is not made use of, the bed consisting of beaten-down earth or ashes. These furnaces have a depth of twenty-four inches, and measure twenty by thirty-two inches at the top, but are somewhat smaller towards the bottom; the twyer, in these, enters one of the narrower

Vermont  
 forges.

Bloomary  
 hearths.



sides of the rectangle. While these are somewhat smaller than the forges at East Middlebury, those lately constructed at Moisie are somewhat larger, measuring thirty by thirty-two inches, the bottom-plate being fourteen inches below the twyer, which is placed nearly horizontal, but of the same size as that described above.

The blast employed in the American bloomaries has a pressure of from  $1\frac{1}{2}$  to  $1\frac{3}{4}$  pounds, and is heated by passing through a series of cast-iron tubes, placed in an upper chamber, above the furnace. These are in the form of inverted siphons, each limb being about seven feet in length, their exterior diameter seven, and their interior diameter five inches. At the East Middlebury forges the air is made to pass successively through three such tubes, heated to dull redness, and attains a temperature estimated at from  $550^{\circ}$  to  $600^{\circ}$  Fahrenheit. The use of the hot blast hastens the operation, and enables the workmen to produce a larger quantity of iron in a given time, than with the cold blast, while, at the same time, it effects a considerable saving in fuel. It is said that where 240 bushels of charcoal will produce a ton of iron with the hot blast, 300 bushels of the same coal would be consumed if the cold blast were used. The quality of the metal is supposed to be deteriorated if too hot a blast is used. With judicious management, however, the use of the hot blast offers great advantages over the cold blast, and has been very generally adopted in the American bloomaries.

Working of  
bloomaries.

The working of these furnaces is conducted in the following manner: The fire being kept active, and the furnace heaped with coal, the coarsely pulverized ore is scattered, at short intervals, upon the top of the burning fuel, and in its passage downwards is reduced to the metallic state, but reaches the bottom without being melted, and there accumulates, the grains agglomerating into an irregular mass or loup, as it is termed, while the earthy matters form a liquid slag or cinder, which lies around and above it, and is drawn off from time to time through the openings in the front plate. At the end of two or three hours, or when a sufficiently large loup is formed, this is lifted by means of a bar, from the bottom, brought before the twyer for a few minutes, to give it a greater heat, and then carried to the hammer, where it is wrought into a bloom; the bloomary fire itself being generally used for re-heating. This operation concluded, the addition of ore to the fire is resumed, and the production of iron is thus kept up, with but little interruption. In this way, a skilled workman will, with a large sized furnace, bring out a loup of 300 pounds every three hours, thus making the produce of the day of twenty-four hours, 2,400 pounds of blooms; in some cases, it is said, 1,500 pounds, and even more, are produced by twelve hours working.

In this connection may be mentioned an arrangement, described and

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figured by Overman, in which the waste heat from the forge, (or rather from <sup>Waste heat.</sup> two forges united,) passes into an oven or stove, placed at a level above the bloomary-fire, and there serves to re-heat the blooms, when it is required to draw them out into bars. A set of small blast-pipes, placed just above the forge, serves to heat a portion of air, which is led into the oven, and there burns any escaping carbonic oxyd gas. The air and gases from the re-heating oven are afterwards employed to heat the blast for the bloomary hearth, in the usual manner. I have not seen this arrangement in operation.

The following observations will serve to give some notions of the working of the bloomary process in the United States. At the Ausable works, as already stated, the somewhat lean ores are dressed so as to yield about fifty per cent. of iron, two tons of ore being required for one ton of blooms, while at the New Russia forges, in Moriah, near Port Henry, where a <sup>New Russia forges.</sup> nearly pure magnetite is employed, three tons of the dressed ore are stated to yield two tons of blooms. When it is considered that perfectly pure magnetite contains only 72.0 per cent. of iron, this proportion of 66.6 per cent., said to be obtained, shows a great economy in working. These figures, furnished me by the proprietor of the forges, Mr. Putnam, were afterwards confirmed by Mr. Pearson, the director of those at East Middlebury, where the very rich ores from the same region are treated. The dimensions and construction of the New Russia forges have already been given. The pressure of blast employed was from  $1\frac{1}{2}$  to  $1\frac{3}{4}$  pounds, and the average produce of iron for each fire, 2,400 pounds of bloom-iron in twenty-four hours; the amount of charcoal consumed being from 250 to 300 bushels to the ton of blooms produced, and the weight of the charcoal from sixteen to eighteen pounds to the bushel.

At East Middlebury, where, as just stated, the conditions are very <sup>East Middlebury forges.</sup> similar, the estimated consumption of charcoal was 270 bushels to the ton of blooms, a result which is the mean of the figures obtained at the New Russia forges. Some of the ores here used contain a little phosphate of lime, and it was observed that when too hot a blast was used, although the production of metal was rapid, the iron from these ores was hot-short, while with the cold blast, formerly employed, the iron, although produced more slowly, was never hot-short. The force of the blast at these forges was equal to one and three-quarter pounds, and even two pounds to the inch. Mr. Pearson, the director of the East Middlebury forges, made, in the autumn of 1867, experiments on several tons of the iron sands from Seven Islands, page 266, and succeeded in obtaining from them about three-eighths of their weight of good iron. He, however, found it necessary, in order to treat these fine sands, to reduce very much the force of the blast, an experience which has been confirmed by the practice at Moisie. It

appears to be from ignorance of this fact, that the bloomers of New York had always rejected the fine sandy ore separated during the process of washing, as being unsuited for treatment in the bloomary fire.

*Moisie forges.*

At Moisie, although eight forges have been constructed, but four of them were in operation at the time of my visit in August, 1868, and the same number, I am informed, in October last, two of the furnaces not having yet been completed. A reverberatory furnace has, since my visit, been constructed, in which it is proposed to re-heat the loupes for the second hammering, instead of returning them, as in most cases is done, to the forge-fire for that purpose. The opening of the twyers used measured one inch by one and seven-eighths; they were inclined downwards at a very small angle, it having been found by experience that the considerable inclination which is used with the coarser ores cannot be advantageously employed with the fine sands. In like manner, as remarked above, it has been necessary to reduce the force of the blast, to from  $\frac{7}{8}$  to  $1\frac{1}{4}$  pounds, the average working-pressure being about one pound to the inch. According to the latest accounts, there were, in October, four hearths in regular operation, requiring four bloomers, one assistant to furnish coal, etc., and one hammerer, being six men in all for each shift of twelve hours. Each hearth furnished eight loupes daily, and the aggregate yield of iron was estimated at three tons, or three-quarters of a ton for each hearth, every twenty-four hours. The consumption of charcoal was 1400 bushels daily, being at the rate of 466 bushels to the ton of blooms, or 350 bushels to each fire. This charcoal is chiefly produced from spruce and fir, with some admixture of birch, the wood being mostly small, and the weight of the coal is stated to be fifteen pounds to the bushel. This gives a consumption of 6990 pounds of charcoal for the production of 2240 pounds of blooms, being at the rate of 3.12 pounds of charcoal for the pound of iron. If we compare this result with the figures given above, for those forges which treat nearly pure magnetic iron ores, we find that to produce a ton of blooms there are consumed, at East Middlebury, 270 bushels, and at New Russia from 250 to 300 bushels of charcoal, weighing from sixteen to eighteen pounds to the bushel. If we assume, in both cases, the greater weight, of eighteen pounds to the bushel, we have for 250 bushels, 4500 pounds, and for 300 bushels, 5400 pounds of charcoal, the former corresponding to 2.01 pounds, and the latter to 2.41 pounds of charcoal to the pound of iron, or, taking the mean of the two, 2.21 pounds, as compared with the 3.12 pounds said to be consumed at the Moisie works.

*Consumption of charcoal.*

*Sizes of hearths.*

If now, we consider the relative sizes of the different bloomary hearths, we find them to be as follows:—

New Russia.....	20 × 32 inches = 6,400 square inches.
East Middlebury.....	24 × 29 " = 6,960 " "
Moisie.....	30 × 32 " = 9,600 " "

The area of the Moisie hearths is, then, in round numbers, one and a-half times that of the others, and, with an equally powerful blast, they should consume one-half more charcoal. This increased size is, however, counter-balanced by the feebler blast, and we find that each fire at Moisie consumes, in twenty-four hours, 350 bushels of charcoal, equal to 5250 pounds, which, from the calculations already given for the New Russia forges, should produce, with an ore such as there treated, 2375 pounds of iron. In fact, the Moisie forges, according to the data before us, with an area one-half greater, consume daily the same weight of charcoal as those of New Russia, and produce only two-thirds as much iron.

I have very recently been informed that, with careful management, it has lately been found possible so far to reduce the consumption of fuel at Moisie, that a ton of blooms can be made with 350 bushels of properly prepared charcoal. The consumption of ore, which formerly amounted to three tons or more for a ton of blooms, is also said to have been considerably reduced, the daily production of iron from each hearth, however, remaining the same as before.

The cause of this small production of iron, as compared with the area of the furnace, and with the consumption of fuel, is not, in my opinion, to be found either in the reduced force of the blast or in the mechanical condition of the ore. A great heat is not required for the reduction of the oxyd of iron to the metallic state, and other things be equal, the finer its subdivision, provided it be not dissipated by the blast, the more rapid and more complete should be its conversion to the condition of metal, by the action of the reducing gases, as it passes downward through the mass of burning charcoal. Such coarse grains of ore as pass, incompletely reduced, through the ignited fuel, and in this state reach the slag below, have no chance of further reduction in the forge. Hence we may conclude that, the fineness of the ore, should, under favorable conditions, render the reduction more complete.

The principal cause of the small yield of the Moisie furnaces is apparently to be found in the incompletely purified condition of the ore. It will be seen in the detailed analyses on page 267, that the iron sand, as now prepared for the forge, may, by the use of the magnet, be divided into two nearly equal portions. One of these is magnetic, and consists, for the greater part, of magnetic oxyd; it contains over two-thirds its weight of iron, and is nearly equal in richness to the magnetic ore used in the New Russia forges. The other half is a highly titaniferous oxyd, mixed with more or less silicious matter, and containing only 44 per cent of iron; and its admixture with the magnetic oxyd, which reduces the proportion of iron in the whole to 55 per cent, appears to be not merely useless, but actually prejudicial.

Causes of the smaller yield.

Nature of ore.

Nature of slags.

Silicious impurities.

When an impure ore of iron is treated in the blast-furnace, certain substances, called fluxes, are added, which form fusible combinations with impurities. Thus, if the ore contains silica, a sufficient quantity of lime is smelted with it, and a silicate of lime is formed, while the oxyd of iron, being left free, is wholly reduced to the metallic state. In the direct method, on the contrary, no fluxes are used, and if silica be present in the ore, it combines with a portion of the oxyd of iron, forming a silicate of iron, which melts into a slag or cinder, from which the iron cannot be separated in the forge. Thirty parts of silica will, in this way, unite with seventy-two parts of protoxyd of iron, equal to fifty-six parts of metallic iron. In the case of the somewhat silicious ores of the Pyrenees, treated in the Catalan forge, we have seen that three-tenths of the iron present in the ore pass into the slag, and the loss would be much greater did not these ores hold a considerable proportion of manganese, lime and other bases, which help to satisfy the affinity of the silica, and to leave the iron free. Such substances as these, play the part of fluxes with a silicious ore, but if they are wanting, a portion of the oxyd of iron itself is consumed for the purpose, forming, in fact, the only flux for the silicious impurities, when such an ore is treated by the direct method in the bloomary fire. Whenever, in the Catalan forge, the American bloomary fire, or any other direct method, we have to treat an ore containing free silica, provided other bases are not present, we must always allow oxyd of iron, in the proportion already indicated, for the saturation of the silica, being at the rate of nearly two parts of metallic iron for each part of silica present in the ore. It is for this reason, it may be remarked, that kiln-burned charcoal is to be preferred, for the bloomary hearth, to charcoal made in piles; the latter being generally more or less impure from adhering silicious earth, which, by combining with oxyd of iron, causes a waste of the ore.

The quartzose sand which is mixed with the iron sands, is nearly pure silica, and the oxyd of titanium which they contain, appears, from the analyses of slags given below, to require, for fluxing it, as much oxyd of iron as the silica itself. These slags, in case no other bases than oxyd of iron are present, should approach very closely to the composition of a tribasic silicate of protoxyd of iron, which, as already explained, contains 30 of silica to 72 of protoxyd of iron, or 29.40 per cent. of silica, and 70.60 of protoxyd, equal to 54.9 per cent. of metallic iron. The highly titaniferous slags produced at the Moisie furnaces, contain, in some cases, a still large proportion of oxyd of iron.

Of the following analyses, I is of a crystalline, black, brilliant magnetic slag, which contained cavities lined with large pyramidal crystals, apparently dimetric in form. It was produced at the Moisie forges in the autumn of 1867. II was a portion of the ordinary slag produced at the time of

my visit, in August, 1868, and was similar to the last, but somewhat vesicular, the cavities being lined with very small brilliant crystals. Both of these slags readily gelatinized when treated, in powder, with hydrochloric acid. The residual silica, however, showed a portion of grains of undecomposed ore, which was larger in the second specimen; it was, in each case, deducted from the analysis. The whole of iron in both of these slags is represented as protoxyd, and the results are compared with those of two analyses of the non-magnetic portion of the ore, copied from pages 267 and 268, and here given under III and IV.

	I.	II.	III.	IV.
Protoxyd of iron .....	67.14	52.31	58.20	56.38
Oxyd of manganese .....	undet.	2.04	.....	1.10
Lime .....	1.37	.....	.....	.95
Magnesia .....	.80	.18	.....	.....
Alumina .....	. . .	.56	.....	.....
Titanic acid .....	20.07	34.05	30.74	28.95
Silica .....	8.75	11.29	6.14	8.75
	<hr/> 98.13	<hr/> 100.42	<hr/> .....	<hr/> .....
Metallic iron .....	52.22	40.68	45.26	43.85

From a comparison of the above analyses it will be seen that the first slag contains more oxyd of iron than the non-magnetic portion of the ore; which, in the conditions of working, at the time the slag was produced, actually dissolved and carried away a considerable portion of the reducible ore. If we were to regard one half of the washed ore as composed of pure magnetic oxyd, this, were it wholly reduced, could only yield an amount of metallic iron equal to 36 per cent; but the magnetic ore, as we have seen, still retains more than 6 per cent of silica and titanic acid, which must be removed by fluxing with a portion of the oxyd of iron present, giving rise to a certain amount of slag. Meanwhile the non-magnetic ore, in melting, removed another portion of iron oxyd, so that when this slag was made, more than three tons of a mixed ore, having the composition above given, must have been consumed for the production of a ton of blooms; while, of the magnetic portion of the ore, one and a-half tons, or a very little more, would suffice. (In the production of the slag II the loss of iron was somewhat less.) This explains why the Moisie furnaces have yielded, when compared with those of New York and Vermont, so small an amount of iron for the labor employed and the fuel consumed. To produce a ton of iron it has been necessary to handle twice as much ore as is required in forges where a pure ore is treated, and moreover one and a-half tons, or more, of worthless material have been fused, and got rid of as slag, thus involving a great waste of fuel, as well as of labor. It may here be remarked that a portion of slag taken by me from the East Middle.

bury forges, contained according, to Mr. Broome's analysis, 48.2 per cent of iron (equal to 62.06 of protoxyd), and 16.70 of silica, besides 17.83 of alumina, and 1.82 of oxyd of manganese. The amount of slag produced by the rich ores which are treated at these forges, is comparatively very small.

It would seem probable that by a judicious management of the working, the waste of iron in the slags at Moisie, might be considerably reduced, and this result, we are assured, has lately been attained; but it will still remain true, that a large amount of iron-oxyd must be consumed to flux the considerable proportions of silica and titanac acid, which are present in the mixed ore, even after careful washing.

Reduction in  
crucibles.

It should here be explained that the result would be far otherwise if this ore, with all its impurities, were to be fused in a crucible with carbonaceous matters, with, or even without proper fluxes. In the former case, as in a blast-furnace, the whole of the iron which it contains, amounting to not less than 55 per cent., might, by judicious admixture, be set free, and reduced; and in the latter cases, without fluxes, it has been shown by Percy, that by fusion at a high temperature, in a crucible lined with charcoal, the tribasic silicate of iron, already noticed, gives up two-thirds of its iron, which is reduced to the metallic state, so that the amount of unreduced oxyd retained by the slag would be inconsiderable. From this it is evident that the results of fire-assays, or trials on a small scale in crucibles, cannot serve as a guide to the working of iron ores in the direct method.

A certain amount of lime added to the ore, would doubtless reduce the waste of iron in the slags, and thus allow more iron to be obtained from the mixed ore; but although such an addition is useful in the blast-furnace, it would require experiments to determine whether the practice could be advantageously introduced in working in the bloomary-hearth. In a region where the ore is so abundant and so cheap as it is at Moisie, the saving of iron is a consideration which should be subordinate to the economy of fuel and labor, and the most profitable way of working these iron-sands would seem to be by separating and rejecting the non-magnetic portion, by some apparatus like that described farther on.

Quality of iron.

The quality of the iron produced at the Moisie forges is superior. As the result of experiments made upon it in England, it is said to possess a tensile strength greater than that of Low Moor iron, and to work easily both hot and cold. It is now employed at Montreal for the manufacture of railway axles.

The fact that those objectionable elements, sulphur and phosphorus, occur in but very small quantities in the iron-sand of Moisie, has already been noticed. It is probably to the absence of these that the excellence of the Moisie iron is due. In a specimen taken from a bloom which was



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made in my presence, at the Moisie forges, the presence of sulphur could be detected by delicate tests, but its amount was only .0094, or less than  $\frac{1}{100,000}$ ; while the quantity of phosphorus present was equal to .0184 per cent. This iron contained no trace of titanium in its composition, and a small mass of white crystalline cast iron, which had accidentally been formed in one of the forges, was equally destitute of titanium.

The cost of producing a ton of iron blooms directly from the ore, by the bloomary process, varies greatly with the price of the dressed ore, which will depend on the proximity of the mine to the forge, and the richness of the crude ore. Thus, the cost of the two tons of dressed ore employed to make the fine iron of the Ausable forges, was estimated by Mr. Rogers, in 1868, at not less than \$18.00, while the one and a-half tons of ore consumed at New Russia, would not probably cost more than one-half that sum. The following estimate made by a highly competent iron-master, in 1868, may serve as a guide to the cost of producing iron at that time in New York:—

Cost of bloom-  
ary iron.

2 tons of ore.....	\$10.00
300 bushels of charcoal @ 8c.....	24.00
Wages.....	9.00
General expenses.....	3.50
<hr/>	
Cost of the ton of blooms.....	\$46.50
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The above prices are in American currency, which, at that time, was equal to about  $\frac{1}{100}$ , making the gold-value \$37.20. The estimate of another manufacturer, in Clinton county, gave \$7.00 for wages. It will be observed, moreover, that the amount of charcoal, in the above estimate, exceeds the average consumption for the production of a ton of blooms, which may be taken at about 270 bushels.

To produce a ton of blooms from cast iron, in what is known in Sweden, as the Lancashire hearth, there are consumed, according to an authority cited by Percy, 23 cwt. of pig iron, and  $\frac{1}{10}$  tons of charcoal. In New Jersey and Pennsylvania the conversion of the pig iron, is, for some purposes, effected by a somewhat similar process, which involves two operations, the melting in the running-out fire, and a subsequent treatment in the sinking-fire, as it is called, which is a bloomary forge very like that used for the ore in the direct method. To produce a ton of blooms in this way, there are consumed 24 cwt. of pig iron, and 100 bushels of charcoal, according to one authority, while another estimate gives 120 bushels; the quantity varying both with the quality of the crude metal, and the charcoal; while, with some arrangements, the consumption of fuel is much

Comparative  
cost.

greater. The mean of these, 110 bushels, at 18 pounds to the bushel, would give, almost exactly  $\frac{2}{10}$  of a ton, the amount used in Sweden. The quantity of charcoal consumed for the production of a ton of pig iron in the United States varies greatly, but in the best constructed and more modern furnaces, like those of Michigan, with rich ores, will not exceed 130 bushels of charcoal of the above weight, which gives, for 24 cwt. of pig iron, 156 bushels. (See page 256.) This, added to 110, equals 266 bushels, the total amount of fuel required to produce a ton of blooms by means of the blast-furnace with the charcoal-finery. There would appear to be but little difference, so far as the consumption of the fuel is concerned, between the cost of producing bloom-iron by the direct and indirect methods just described. The first cost of the establishment for the former is, however, less, and this is probably one of the reasons which has led to the adoption of the direct method by the bloomary forge in northern New York.

The conversion of the oxyd of iron to the metallic state, under the influence of solid carbonaceous matter, or reducing gases, takes place at a temperature considerably below that at which the affinity of silica for the oxyd of iron is exerted. Even the compound of titanic acid with oxyd of iron is decomposed at a red heat in contact with hydrogen gas, the iron being wholly reduced to the metallic state. If it were possible to effect this reduction, and subsequently to eliminate the silica and titanic acid from the metallic iron, ores containing these impurities might be made available for the direct method of conversion; but the practical difficulties of effecting such a separation are such that the only available modes of treating such ores as contain considerable amounts of these impurities, are to smelt them in the blast-furnace with proper fluxes, or to effect as complete a separation of the impurities as possible, before submitting them to the process of reduction. This, in the case where heavy granular ores are mixed with quartz and feldspar, as for example, at the Palmer ore-bed, already noticed, is attained by washing away the lighter materials. Where, however, the impurity is chiefly titaniferous iron, as in the Moisie sands, the separation may be readily effected by means of magnets, a process which is equally advantageous where magnetic iron ore is mixed with lighter impurities, as quartz or silicious minerals.

Purifying ore.

The use of magnets for this purpose has long been taken advantage of, and various machines with permanent and with electro-magnets have been contrived. A simple and ingenious arrangement for this end, which has been invented and patented by Dr. F. A. H. Larue, of Laval University, Quebec, appears to be novel in the mode of its working, and is very efficient and cheap. The mixed sand or crushed ore is poured through a screen, into a hopper, the discharge of which is so arranged as to open and close at proper intervals of time, and, falling from this, is spread

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in a thin and uniform layer, upon a series of aprons arranged, with interspaces, between two parallel endless bands, which pass over two horizontal cylinders. These aprons, charged with ore, are made, by the movement imparted to one of the cylinders, to pass from beneath the hopper, and under a series of permanent horse-shoe magnets, 800 in number, each capable of sustaining about five pounds weight, arranged upon transverse bars, in five rows of 160 magnets each. Beneath these is a tympan, covered with muslin, which, when the iron ore is passing beneath them, is in the contact with the poles of the magnets. So soon, however, as the magnetic portions of the ore have arranged themselves, by magnetic attraction, in adhesion to the under side of the tympan, and the apron has moved from beneath, and gone forward to discharge the non-magnetic portion of the ore at the foot of the machine, the tympan is momentarily withdrawn a short distance from the poles, and the adhering magnetic ore falls in the open space between two aprons, into a receptacle placed below. This process of loading and unloading the magnets can be repeated twice in each minute.

Larue's mag-  
netic machine.

These machines, as now constructed, occupy a space of about six feet by five, and are four feet high; they are said to cost, at Quebec, at about \$500 each. One, of these dimensions, will, according to Dr. Larue, treat in an hour, three tons of sand holding one-third of magnetic ore, separating from it one ton, containing over ninety-nine per cent of magnetic grains. I have myself seen only a smaller machine, the first one constructed, which had a capacity of about one-half that just stated. The motive power required is very small, and the mechanism, as will be seen from the description, exceedingly simple. Dr. Larue observes, that, inasmuch as a rich sand may be passed through the machine as rapidly as a poor one, the yield is directly proportionate to the amount of magnetite present, so that a sand containing one-fourth as much as that above mentioned, would yield about six tons of purified sand in twenty-four hours. Even very poor sands may, probably, with this machine, be treated with advantage. The same process of purification may doubtless be applied with advantage, after crushing, to the preparation of lean massive magnetic ores for the bloomery fire, or for other direct methods for conversion into iron and steel. A process of partial reduction, at a low red heat, will render non-magnetic iron ores attractable by the magnet, a reaction of which Chenot long since proposed to take advantage, for the purification of such iron ores as are not naturally magnetic.

In accordance with the well-known fact that the reduction of oxyd of iron takes place at a temperature very much below that required for its subsequent carburization and fusion, it has been shown that the charge of ore in a blast-furnace is converted to the metallic state some time before it

Various direct  
processes.

descends to the zone in which melting takes place. It forms, when reduced, a spongy mass, readily oxydized, which, by proper management, can be compressed and made to yield malleable iron, or by appropriate modes of treatment, may be converted into steel. This fact has been the starting point of a great number of plans designed to obtain malleable iron and steel, without the production of cast-iron and the employment of the processes of puddling and cementation. This, it is true, is attained in Catalan and bloomary forges, but the attention of many inventors has been, and still is, directed to the discovery of simpler, or at least of more economical methods of obtaining similar results. A short sketch of the various new processes will not be without value, as bearing upon the utilization of the iron ores of Canada, and especially of its iron sands.

Chenot's  
method.

Of these, the method of Chenot is best known. His experiments seem to have been commenced about forty years ago, since we are informed that he had erected a large furnace for the direct treatment of the ores of iron, in 1831, although his results were not brought before the public until twenty years later, at the International Exhibitions of 1851 and 1855. I was a member of the International Jury at the latter, and had an opportunity of studying Chenot's process as then conducted, on an industrial scale, at Clichy, near Paris. A description by me of the process as then and there practised, will be found in the report of the Geological Survey for 1855-57 (page 397). Rich peroxides were broken in small pieces, mixed with a portion of charcoal, placed in large vertical rectangular muffles or retorts, enclosed in a gas-furnace, and heated to redness. The ore, after being reduced to the state of metallic sponge, passed downwards into an air-tight cooling-chamber, which was a continuation of the muffle, and when sufficiently cooled, was withdrawn. The spongy metal, thus obtained, was then exposed to a welding heat in a proper furnace, and formed into balls, which were afterwards treated like the balls from a puddling-furnace, and gave malleable iron. By impregnating the metallic sponge with oily and tarry matters, and afterwards expelling these by heat, a sufficient amount of carbon was fixed in the metallic sponge to convert it into steel. By grinding, compressing and melting this carbonized sponge, cast-steel of a superior quality was manufactured at prices which, it was claimed, were much below the cost of steel prepared by cementation of bar iron. This process was subsequently introduced in several places in France, Belgium and Spain, where it was applied to the manufacture of bar iron, and up to 1863 at least, was worked on a considerable scale at Baracaldo, in Spain, where, in 1859, about ten tons of iron were manufactured daily from iron sponge.

A very important modification of the process already described, in which the heating was effected externally and indirectly, consisted in the

internal or direct method of heating. In this the outer furnace and the admixture of charcoal with the ore were both dispensed with. The vertical reduction-chamber was filled with ore only, which was reduced by the action of currents of heated carbonic oxyd gas, obtained by forcing air, at a pressure equal to half an inch of mercury, through two generators filled with ignited charcoal. This mode of producing the sponge was found much more economical than that by indirect or external heating. The working results of the direct method, as carried on at Lamarade, in Spain, in 1863, are given by Percy; from which it appears that for the production of one ton of blooms, there were consumed 1.87 tons of charcoal. The greater part of the fine Swedish iron used at Sheffield for the manufacture of steel, is produced from charcoal-made pig, treated in a charcoal-finery, known as the Lancashire hearth, and is obtained with a consumption of charcoal, which, for the united processes of reduction and refining, amounts to 1.90 tons for the ton of blooms, a result almost identical with that of the process of Chenot. (Percy, *Metalurgy*, pp. 342-596.) The modified Catalan forge, and the American bloomary fire, as we have seen, produce malleable iron with a consumption of charcoal which is not very much greater, and with a simpler, and probably less expensive apparatus than that required for the Chenot process; while the method by the blast-furnace permits of the use of ores which are unfit for treatment by any of these direct processes.

Chenot's direct heating.

Comparative cost.

The patents granted to Clay, in England, in 1837 and 1840, were for the manufacture of malleable iron by a process essentially the same with Chenot's earlier method of indirect or external heating. According to Clay, hematite ores were mixed with one-fifth of their weight of charcoal, coke, or other carbonaceous matter, and heated to bright redness in a clay retort, or other suitable vessel, until the ore was converted to the metallic state. When the reduction was complete, the spongy iron (without previous cooling, as in Chenot's plan,) was transferred directly to a puddling-furnace, where it was brought at once to a welding heat, made into balls, and then wrought into blooms in the usual manner. This process was tried on a pretty large scale near Liverpool, in 1845-46, and although iron was regularly made by it for some time, and to the amount of 1000 tons, the process was not found to be commercially profitable, and was abandoned.

Clay's method

The process of Renton, patented in the United States in 1851, was very similar in principle and mode of working to that of Clay. The mixture of ore and coal was introduced into a vertical muffle or retort, which was inclosed in the flue or chimney of a furnace, not unlike an ordinary puddling-furnace. The contents of the muffle, being sufficiently heated, were reduced to the metallic state, and, from time to time, discharged from

Renton's process.

Harvey's process.

the bottom, into the furnace, where the spongy iron was exposed to a welding heat, and wrought into blooms. This process, after having been essayed on an industrial scale at Cincinnati, and at Newark in New Jersey, was abandoned. A similar fate attended the trials, on a large scale, of Harvey's patented process, at Mott Haven, near New York, about the same time. In this, the coarsely powdered ore, mixed with charcoal, was placed on inclined trays or shelves of steatite, in a heated chamber connected with a welding or balling-furnace. The flame from a fire below was made to pass through the chamber, and the ore, being at length reduced to the metallic state, was transferred to the hearth below, and there converted into blooms. For a farther description of these various processes, and the similar plan of Yates, the reader is referred to Percy's *Metallurgy*, pp. 330-348.

Gurlt's patent.

Chenot's plan of reducing the ore by a current of carbonic-oxyd gas, was adopted by Gurlt, who used the direct mode of heating, already noticed. The gases from the generators charged with fuel, were led through flues, into the vertical reducing-chamber, a blast of air being at the same time introduced into the flues, in sufficient quantities to keep up the combustion of the gases. By this means, according to the specification, "there passes into the shaft a mixture of flame and carbonizing and reducing gases, by which the iron ore is heated" and carbonized. According to Gurlt's patent-specification, (No. 1679, London, July 16, 1856,) by continuing, for a sufficiently long time, the action of the gases, the resulting iron sponge may be more or less carbonized, so as to yield, by subsequent fusion, either cast iron or steel. These partially carbonized products he proposed to melt in a reverberatory gas-furnace, the blast of air into which is to be "so regulated that it exactly burns the gas produced in the generators," and that neither unburned gases nor unconsumed air escape; the object being to obtain a neutral flame, which should not alter the sponge upon the hearth. In this way carbonized sponges from rich ores, are said to have been successfully converted into cast iron in Spain.

Gurlt's ingenious specification thus involves the idea of first reducing the iron ore to a metallic sponge, and afterwards carbonizing this sponge, so that, by subsequent fusion, it may be converted into cast iron or steel. Although the conception of thus carbonizing the iron while in a spongy state, is probably novel, the use of carbonaceous gases or vapors for carbonizing iron, and converting it into steel, is not new, as may be seen from the patent for this purpose granted to Macintosh in 1825. The experiments of Percy upon iron wire have also shewn the rapid carbonizing effect of coal-gas and heavy oily vapors, like those of paraffine; (*Metallurgy*, pages 109 and 773) and, according to Marguerite, carbonic-oxyd gas, at

an elevated temperature, yields up a portion of its carbon to iron, which is thus converted into steel. Practical difficulties have hitherto prevented the application of hydro-carbon gases and vapors to the carbonizing of bar iron on a large scale.

With the results of Chenot, Gurlt, and Macintosh before us, we are prepared to understand the process of Dr. George Hand Smith, of Rochester, New York, which is just now attracting some attention in the United States, for the production of steel. The crushed and purified ore, or iron sand, mixed with a portion of pulverized charcoal, is heated in a kind of reverberatory furnace, with an arrangement which permits the vapor of petroleum or coal-tar to pass through the mass, thus aiding in the reduction, and finally carbonizing the resulting sponge, which is then transferred to a puddling-furnace, to be wrought into iron, or, if properly carbonized, into steel.

Before proceeding farther, mention should be made of some other methods which have been devised for the treatment of iron sands, and for their conversion into iron or steel. In 1851 a patent was granted to Stenson, for a process for working the iron sands of New Zealand, and similar ores from India. These were to be mixed with small portions of clay and lime, with or without the addition of charcoal; the mixture was ground in a pug-mill, with water, and formed into lumps, for subsequent treatment in the blast-furnace. In 1862, Moreau proposed to mix iron sands with iron filings or turnings, and then incorporate them with fuel, such as peat-coal or coke; the mixture being made into blocks, which were to be smelted in suitable furnaces. In 1866, Mr. James Hodges, who was not acquainted with the experiments of Moreau, moulded the iron sands of Moisie into blocks with peat, and by treating these, after drying, in a proper furnace, succeeded in converting the ore into malleable iron, at a single operation. (*Report of Geological Survey for 1866*, p. 291.)

Plans for working iron sands.

Messrs. Whelpley and Storer of Boston effect the reduction of the iron sand ore, or pulverized ores, on the hearth of a reverberatory furnace, which is heated, in part, by pulverized coal, borne by a blast of air over the fire of solid coal upon the grate. In this way the furnace-chamber is filled with a volume of burning coal-dust, which can, by regulating the supply of coal and of air, be made either oxydizing or reducing. The heated ore upon the furnace-hearth is thus reduced to the metallic state, balled and made into blooms, with, it is claimed, a great economy of fuel.

It has also lately been proposed to convert these sands into steel or cast iron, by melting with a sufficient admixture of charcoal in crucibles, or other closed vessels, heated from without. This is, in fact, nothing more than an extension of the dry method for assay of iron ores. A patent for making steel in this way, by treating rich ores, mixed with carbonaceous



Steel direct from  
the ore.

matter, in air-tight melting-pots, was granted to Lucas, in 1791, and a similar claim was made by David Mushet, in 1800; while, according to Percy, "experiments in the direct production of cast steel from iron ores, in crucibles, were made by Riley, at Dowlais, a few years since, and although excellent steel was occasionally produced, it was not found possible to ensure uniform results." (*Metallurgy*, p. 765.)

Ponsard's  
results.

More recently, Ponsard has brought forward a similar process, the results of which were communicated to the French Academy of Sciences, July 19, 1869. This arrangement consisted of a number of fire-proof crucibles, about eight inches in diameter and forty inches high, which were placed in a reverberatory gas-furnace, the mouths of the crucibles being fitted into openings in the furnace-roof, for convenience of charging. The lower part of the crucible is perforated, and rests on the sole of the furnace, which is furnished with gutters leading to a depression or basin in the middle of the furnace-hearth. The crucibles are charged with the ores, mixed with proper fluxes, and about twelve per cent. of carbon, sufficient to effect the reduction and carburization of the iron, which, under the influence of a very intense heat, melts, and, running through the holes in the bottom of the crucible, collects in the basin in the middle of the furnace. According to Ponsard, a ton of coal is consumed for each ton of iron produced, so that the process cannot be recommended for its economy of fuel. He, however, claims as a great merit of this process, the complete separation of the fuel from the carbon required for the reduction of the ore, so that for the furnace, inferior kinds of combustibles, which, if brought directly in contact with the ore, would injure the quality of the metal, may be used with safety and advantage.

Johnson's  
patent.

The process patented by Johnson, Jan. 22, 1868, as described in the *Practical Mechanics' Journal* for June, 1869, (quoted by Osborn in his *Metallurgy of Iron and Steel*, page 868) is, however, exactly similar, in all its details, to that of Ponsard, which was first announced as a novelty to the French Academy, July 19, 1869, eighteen months later. In a specification dated at Quebec, July 16, 1869, Dr. Larue claimed, and subsequently received letters-patent for Canada, for a process similar in design to that of Johnson, of which he was ignorant. Although there were differences in detail, the avowed object in both plans was to separate the ore, with the carbon required for its reduction, from the fuel, (which might, consequently, be of an inferior quality,) and to permit of a continuous charging and discharging of the crucible. The difficulty of constructing sufficiently refractory crucibles for the intense temperature, and the small yield to be expected from such a process, would perhaps prevent it from ever being used for the manufacture of cast iron. Dr. Larue, however, anticipated its application to the production, not of cast-iron, but of cast-steel, which

Larue's patent.

would require a very nice adjustment of the proportions of carbon to secure a uniform quality in the product; as in the ancient processes of Lucas and Mushet, and the more recent experiments of Riley, mentioned by Percy, and referred to above.

Two processes for the production of steel are those which depend, respectively, on the combination of cast iron in proper proportions with malleable iron or iron sponge, and with oxyds of iron. In the specification of a patent granted in 1839, Heath claimed the production of steel by melting with cast-iron, either wrought iron, or oxyds of iron or manganese. In a second patent, granted to him in 1845, he described an arrangement by which the cast-iron was kept in a molten condition, in a gas-furnace, while pure iron in scraps, or in sponge, obtained by reducing oxyd of iron, as in Chenot's and Clay's method, was added from time to time; until, by trial, the proper quality of metal had been obtained, after which the liquid steel was run into ingots. Other processes, based on the reactions embodied in Heath's first patent, are those of Uchatius, (patented in 1855,) who melts granulated cast iron in crucibles, with a certain proportion of pure oxyd of iron, and thus obtains a fine quality of steel, (a process already specified in Wood's patent, in 1761); and that of Brown, (patented in 1856) who, to produce steel, melts, in crucibles, mixtures of pig iron and clipped bar iron. This method is practised to some extent in Sweden, where it is known as the Obersteiner process.

In the process of Obuchow, which appears to be successfully used in Russia, fine pig-iron is melted, and run into a large crucible, previously heated to whiteness, and holding magnetic iron ore, alone, or with titanic iron sand and iron and steel scraps. The crucible is then heated till the contents are perfectly fluid, some nitre and arsenious acid are added, and the steel run into ingots. By a somewhat similar process to this, Ellershausen attempted to produce steel, by pouring molten cast-iron upon previously oxydized sheet-iron, heated to redness, and placed in a heated vessel. The oxyd dissolved in the molten iron with violent chemical action, decarbonizing it, and producing a kind of steel; but it would probably be difficult to effect a thorough conversion of the iron without keeping up the heat from without; which was not done in Mr. Ellershausen's first experiments, made in Montreal, in the spring of 1868.

The above processes, however, involve the use of crucibles, and it had become a great desideratum to produce cast steel upon the open hearth. This was the aim of Heath, in his process described above; but the difficulties in producing and controlling a heat sufficient for the purpose, were so great as to render the efforts in this direction but partially successful, until the regenerative gas-furnace of Siemens placed in the hands of metallurgists the means of fusing large bodies of steel on the hearth of a

Cast steel.

Heath's patents.

Obuchow's method.

Ellershausen's plan.

Martin's steel  
process.

reverberatory. Provided with this, the Messrs. Martin, of Sireuil in France, have succeeded in producing cast steel, in charges of three and four tons at a time, by melting down wrought iron in a bath of cast iron, by what is now known as the Siemens-Martin process. The products thus obtained, attracted much attention at the Paris Exhibition, in 1867, and the process has since been widely adopted in Europe and in the United States; where it was first introduced by Messrs. Coeper, Hewitt & Co., and is now in successful operation at their works at Trenton, New Jersey.

Its operation.

Beginning with a bath of six hundred weight of pig iron on the hearth, malleable iron, as puddle-bars, for instance, is added, previously heated to whiteness, and rapidly dissolves in the molten cast iron, until, at the end of about four hours, the charge amounts to three tons, and will be found to consist of a soft, nearly decarbonized metal. It is then recarbonized by the addition of from five to eight per cent. of spiegeleisen (manganesian cast iron), as in the Bessemer process, and run in moulds. The bath of molten metal, during the process, is protected by a covering of fused slag or cinder.

The furnace-bottom for this process is made up of a silicious sand, which must not be quite pure, but contain some alumina or other bases, so that, under the influence of the high temperature, it may harden, without melting, forming an impervious crust, which will resist, for a considerable time, the action of the molten steel. The upper part of the furnace is built of Dinas fire-brick. Attempts have been made to use an admixture of oxyd of iron with the pig metal, in this process; but it is found that the corrosive action of the oxyd, at a high temperature, upon the furnace-bed is such as to preclude its employment. The entire cost of a furnace with a capacity of producing three tons of cast steel, with gas-producers, generators, and all the apparatus for moving the ingot-moulds, is, in England, about £500 sterling.

Bessemer's pro-  
cess.

This process, it is true, cannot compete with the Bessemer or pneumatic method for the cheap production of cast steel in large quantities; but while the latter is applicable only to certain fine kinds of cast iron, comparatively free from phosphorus and sulphur, the process in the open hearth permits the employment of other qualities of iron. These, in being reduced, by puddling or otherwise, to the condition of malleable iron, are deprived of the impurities prejudicial to steel, before being added to the iron bath. While, therefore, the Bessemer process will probably remain without a rival for the treatment of the purer cast-irons, the production of steel by the open hearth will perhaps become even more important, because of wider application. The Heaton process, for which so much was claimed as a method for the production of steel from impure cast iron, by the action of nitrate of soda, appears, from the late careful studies of

Heaton pro-  
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Gruner, destined to become subsidiary to the production of steel in the open furnace. Gruner concludes that it "can never, from any point of view, become a substitute for the Bessemer and Martin processes. These produce ingots of steel, or homogeneous iron, from pure brands. The Heaton process deals with impure brands, and seeks to convert them into a refined metal, more or less purified, the treatment of which has to be finished in a Siemens furnace." He further declares that the only advantageous way of treating the products of the action of nitrate of soda on cast iron, is to submit them to the Siemens-Martin process. (*Annales des Mines* for 1869, fifth part.)

Mr. Bessemer has very recently made experiments upon the working of his process, under pressure, by which he obtains such an elevation of temperature, as, it is expected, will enable him to introduce malleable iron into his converters, and thus effect in them what Martin does upon the open hearth. In the mean time Siemens has, by the aid of his furnace, been able to carry out a part of the original plan of Heath, who, in 1845, proposed to reduce iron ores, by heating them, in small fragments, with charcoal, in a close vessel, as in the methods of Chenot and Clay, and to add the resulting spongy iron to the bath of molten cast iron. The reduction is, by Siemens, effected by a plan which combines the indirect and direct methods of Chenot.

Siemens's direct process.

Above the furnace, and immediately over the bath of molten cast iron, which occupies the hearth, are two large tubes of refractory clay, enclosed in an outer casing, through which the flame from the furnace passes, and allows these tubes, or reduction-chambers, to be heated, with their contents, to redness. They are charged from the top with finely broken rich ore, through which a current of previously washed and purified carbonic oxyd gas, from the common gas-generator of the furnace, is forced, and reduces the ignited ore to the condition of a metallic sponge of pure iron; this, descending, is at once dissolved in the molten cast-iron bath, and effects its conversion to steel, precisely as in Martin's plan, where solid malleable iron is made use of. In certain cases, as with very finely divided ores, the reduction is effected by an admixture of about ten per cent. of charcoal, or other carbonaceous matter.

Siemens has already manufactured excellent cast steel by this method, and there is no doubt that, in the case where pure oxyds, free from sulphur and phosphorus, can be obtained, the mode of directly producing steel with spongy iron may be advantageously employed.

A simple and ingenious process, based, like that of Siemens, on the original suggestion of Heath, has recently been devised and patented by Mr. Robert G. Leckie of Montreal. Having found that when finely-divided iron ore, as magnetic iron-sand, was made into lumps with peat,

Leckie's patent

coal, or other carbonaceous matter, not in excess, and exposed to redness, out of a current of air, there results a nearly pure spongy metallic iron, he proposes to obtain iron in this way, and add it to the bath of molten cast iron, in a reverberatory gas-furnace. The ore, agglomerated with the reducing material, is to be placed in one or more large chambers or ovens, in the rear of the hearth, and, when sufficiently heated to effect its reduction, is to be added to the bath of molten iron. He expects soon to test, on a working scale, this mode of making cast steel in the open hearth, to which the purified magnetic iron sands of Canada, from their freedom from sulphur and phosphorus, would seem to be peculiarly well adapted.

It is one of the great advantages of the Siemens furnace, that by a judicious regulation of the supply of air, and by proportioning it to the gaseous fuel, it is possible to obtain, at will, either an oxydising, a reducing, or a neutral flame; a point of much importance in the fusion of metals in the open hearth, which was already indicated in Gurlt's specification, as explained on page 46.

Siemens's  
regenerative  
furnace.

The employment of gaseous combustibles has been greatly extended since the successful use of the regenerative principle by Siemens. This consists in allowing the heated gases, after combustion in the furnace-chamber, to pass out, downwards, through two chambers packed with fire-bricks, so arranged as to allow a free passage of air between them, to which they impart their heat; the waste gases passing off into the stack at a temperature seldom above 300° Fahrenheit. After an interval of from half-an-hour to an hour, the current is changed, and the gases are led off through another pair of regenerators; while those which had been heated by the escaping gases are now used to conduct the air and gas for keeping up the combustion; these passing in through the heated regenerators, have their temperature greatly raised before entering the combustion-chamber. By alternately making each pair of regenerators the channels for the passage of the gases to be burned, and for the waste products of combustion, a very intense temperature is maintained in the chamber, with very little loss of heat.

Burning wet  
fuel.

Coal and dry wood have generally been used in the gas-generators, where, by a partial combustion, the solid fuel is converted into combustible gases. With wet fuel, a large amount of steam becomes mingled with the gases, where its presence is very objectionable. This difficulty has, however, been entirely obviated by a system lately devised in Sweden, which may become of great advantage to Canada. I have therefore thought it best to copy from Mr. Abram Hewitt's Report on the Production of Iron and Steel at the Paris Exhibition of 1867, the following account of this valuable invention. This report, published by the United-States Government, contains excellent drawings of the furnace:

"The furnace devised by F. Lundin, of Carlstadt and Munkfors, is designed for the consumption of turf and peat, without drying, and of wet saw-dust or other moist fuel; an invention deemed so valuable that the association of Swedish iron-masters have rewarded Lundin by a gift of \$10,000, which, in Sweden, is a very considerable sum. In this furnace, the fuel is fed by a hopper, into a reservoir resting upon an inclined grate, supplied from below with air from a blower. The products of the combustion thus maintained, pass through a condenser, where all the moisture in the gas is condensed. The gas then passes to the heating-furnace, which is furnished with Siemens's regenerators."

It is found easy to use fuel holding as much as forty-five per cent. of water. The gas, as it issues from the producer charged with such wet fuel, contains one fourth its weight of watery vapor. It passes at once into a chamber in which, from perforated pipes, small streams of cold water are discharged, crossing each other in various directions, and filling the chamber. By this, the gas is greatly cooled, and the acid and tarry matters present, with much of the steam, are condensed. It then passes through a second chamber, filled with wrought-iron bars, arranged like the bricks in the heat-regenerators, and kept cold by a stream of water trickling over them. The gas, which at the time of its escape from the producer, was heated to the melting point of lead, is thus cooled down until it retains only four per cent. of watery vapor.

"The expense of building a full-sized furnace, in Sweden, is about \$2500 in currency, and it is estimated that such a furnace will utilize 1700 tons of fuel in a year, at a saving proportioned to the cost of other fuel in the particular locality where it is employed. In Sweden, it is estimated that the annual saving, resulting not merely from the fuel, but from the repairs of the furnace, and the increased temperature, amounts to over \$5000 per annum, on the product of each furnace. \* \* \* \* \* The gas produced by seasoned wood contains more water than that which proceeds from the Lundin condenser. The duration of the furnace is simply surprising, and is to be attributed, probably, to the fact that there is no cinder. In eight weeks, the thickness of the roof, four inches, was only diminished from  $\frac{1}{2}$  to  $\frac{1}{4}$  inch, and the side-walls were entirely uninjured. So wonderful is the success of this system of condensation, in connection with the Siemens regenerators, that, in Sweden, and, in fact, everywhere where moist fuel is employed, the Lundin furnace will supersede every other. Its great merit is, that it is available for any kind of fuel whatever. In the United States it is believed that this arrangement might be employed advantageously for washing the gas obtained from mineral coal; but its chief merit consists in the fact that in mineral regions, far removed from the coal fields, it is possible to establish iron,

Lundin's furnace.

works, using saw-dust or peat with entire success and great economy. In the lumber regions of Lake Superior it will be found to have a special value, because there is an abundant supply of pig-iron, accessible to the saw-mills on Green Bay and in Michigan, producing enormous quantities of saw-dust, slabs, and waste timber."

By the aid of the Lundin furnace, combined with the regenerators of Siemens, Rinman has succeeded in producing steel by the Martin process, using only pine saw-dust for fuel. When such results can be obtained with saw-dust, or with ordinary peat, the want of mineral coal need no longer be an obstacle to the development of the metallurgical industry of this country.

Boëtius's furnace.

The gas-furnace of Boëtius, which is now used for zinc-smelting, and in many glass-works, in France, is simpler and less expensive than that of Siemens. It does not make use of the regenerative principle, and hence the waste heat can be employed in boilers or for other purposes. In this furnace, however, there being no condenser as in the Lundin system, only dry fuel can be made use of. The air which serves to burn the combustible gases in the furnace-chamber, is heated by passing between the walls of the generator and an outer casing, these walls being made very thin, and supported at intervals, by bricks, which are built both into them and their envelope. This furnace does not enable us to obtain a heat sufficient for the production of cast steel, but is well adapted for puddling and reheating iron, as well as for zinc and glass-works, and is said to economize from 30 to 33 per cent. of the fuel. This description is taken from a paper by Gruner, professor of metallurgy at the Ecole des Mines of France, which appears, with working-drawings, in the *Annales des Mines* for 1869, fifth part. The same paper contains, also, descriptions, with drawings, of the Siemens-Martin steel process, besides an account of Ponsard's experiments, and of the Ellershausen process.

#### THE ELLERSHAUSEN PROCESS FOR MALLEABLE IRON.

The removal from cast iron of its carbon and silicon, and its conversion into malleable iron, is chiefly effected in two ways: of these the first consists in melting down the pig metal, before the blast, in an open fire known as a hearth-firery or bloomary, somewhat resembling the bloomary hearth used for the direct process of reduction in the United States. In the second method, the metal is melted and decarbonized in reverberatories, known as puddling-furnaces. In the puddling process the carbon of the iron is removed, partly by the oxygen of the air, and partly by that of the oxyd of iron, which, in the form of iron ore, is used for lining, the sides

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of the furnace, or fettling, as it is called, for which purpose large quantities of magnetic and hematite ores are consumed.

In both of these processes the cast iron is melted, but there are two methods, which have long been known, in which the decarbonization of cast iron, and its conversion into malleable iron, are effected without fusion. In one of these, small objects of cast iron are imbedded in pulverized hematite ore, in carefully closed crucibles, and are then exposed for three or four days to a red heat; when, if the size of the castings is not too great, they are found to be decarbonized, and changed, throughout, into soft malleable iron. In this way are prepared the so-called malleable castings. Malleable castings. Very similar to this, in principle is, a process practiced in Wales some half a century or more since, and described by Percy, after Mushet (*Metallurgy*, Old Welsh process. p. 803). Granulated or shotted cast iron was mixed with a certain proportion of bloomary cinder, rich in oxyd of iron, and the mixture exposed for some hours, in covered crucibles, to a red heat. At the end of this time it was found that the grains of iron were decarbonized, and capable of being welded together; having been, in fact, converted into malleable iron by the action of the iron-oxyd.

By another process, the use of the oxyd of iron is dispensed with, and the iron is kept at a red heat, in contact with the air. In Tunner's method, Tunner's method. plates of cast iron, from one-half to three-fourths of an inch thick, are packed in boxes of quartz sand, so arranged as to permit the passage of air, and exposed to a glowing red heat for several weeks; at the end of which time the metal is found to be decarbonized, and converted into malleable iron. The impurities which form fusible slags, appear, in these methods of producing malleable iron, to be separated in a liquid form; sweating out, as it were, from the pores of the iron.

With these facts in mind, we are prepared to understand the results obtained by Mr. Ellershausen, which have given rise to the process bearing his name. In 1868, while making experiments on the production of steel, he endeavoured to incorporate coarsely pulverized oxyd of iron with molten pig metal, with the intention of subsequently melting down the mixture, and thus obtaining cast steel, by a process essentially the same with that of Wood and Uchatius (page 293). Ellershausen's discovery.

He found however, that the composite ingots of ore and pig metal, when heated on the hearth of a reverberatory furnace, did not fuse, but that the metal was rapidly decarbonized, and, with the separation of a considerable amount of liquid slag, converted with malleable iron, which could be taken at once to the squeezer, and rolled into bars of a quality superior to those produced by the method of puddling.

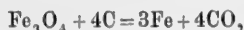
It might at first appear that, as in the production of malleable castings, the mingled oxyd of iron was the sole agent in thus decarbonizing and

Theory of the  
process.

effecting the conversion of the metal, but subsequent experiments have shown that by reducing the proportion of ore much below that required, by theory, to effect the change; and even by replacing a portion of the ore by powdered charcoal, whose effect would seem to be the reverse of oxydizing and decarbonizing, as good results were obtained as before. In the pig-bloom, as the aggregate of pig metal and ore is termed, the iron is much subdivided, being partly in grains, and partly enveloping the granules of iron ore; the whole forming a somewhat porous aggregate, which is pervious to air, and thus offers a great extent of surface to its oxydizing action, as well as to the action of the intermingled oxyd of iron. Where an admixture of charcoal is used, it would soon be destroyed by combustion, and by the action of the accompanying iron-oxyd, and the mass rendered still more permeable to the air; so that the finely-divided white cast iron of the pig-bloom becomes rapidly decarbonized under the joint influences of the oxygen of the air and that of the ore. The ore, being in part reduced to the metallic state by the carbon and silicon of the cast iron, tends to make the loss of iron less than in the puddling process. In this view, the Ellershausen method unites the reactions of the process for malleable castings, and the Welsh process above described, where oxyds of iron are the decarbonizing agent, with that of Tunner, in which the decarbonization is effected by the oxygen of the air.

If we suppose the oxygen of the mingled iron ore to be the sole decarbonizing and purifying agent, the reaction would be as follows: the carbon of the pig iron, with the oxyd of iron, would give rise to metallic iron and carbonic-oxyd gas; while the silicon, which the crude metal always contains, in variable quantities, would reduce another portion of the oxyd, liberating metallic iron, and forming silicic acid. This, in its turn, would unite with a portion of unreduced oxyd of iron, to form a fusible silicate or slag, of the composition already referred to on page 282.

If we take the magnetic oxyd of iron, the reaction with carbon would be represented by



while with silicon we should have



The above equations lead to the following results for each unit of carbon and silicon in the pig iron:

1 carbon requires 4.83 magnetic oxyd, and gives iron 3.5, carbonic oxyd 2.33  
1 silicon " 8.28 " " " " " 2.0, silicate of iron 7.28

Thus a pig iron holding, for example, 95.00 per cent. of iron, 4.00 per cent. of carbon, and 1.00 of silicon would require,

$$4 \times 4.83 = 19.32 \text{ of magnetic oxyd.}$$

$$1 \times 8.28 = 8.28 \text{ " " "}$$

$$\hline 27.60 \text{ " " "}$$

and should yield 16 parts of reduced iron, and 7.28 of silicate of iron. In the case of some pig irons, which, in addition to 4.0 or 4.5 per cent. of carbon, contain 2.0, or even 2.5 per cent of silicon, the quantity of magnetic oxyd required, according to the above formulas, would be greatly increased. In the trials on a large scale, for the production of malleable iron by the Ellershausen method, at Pittsburg, Dr. Otto Wuth made careful analyses of the pig metal, and the resulting products, both iron and slag. From these analyses it appears that when 100 parts of a metal, holding over 1.0 per cent. of silicon and 4.2 per cent. of carbon, were mixed with from 28 to 30 parts of magnetic or hematitic iron ore, and treated as above described, the silicon, and nine-tenths of the carbon were removed, together with most of the sulphur and phosphorus. At the same time the resulting slag was much richer in iron than that obtained in puddling the same iron, or, indeed, than most slags from the puddling-furnace. It contained an amount of iron equal to not less than 64.7 per cent. of metal, and but 8.95 per cent. of silica, while the saturated silicate of iron, whose formula is given above, contains but 54.9 per cent. of iron, and 29.4 per cent of silicon. The highly basic slag from the Ellershausen process, as analyzed by Dr. Wuth, has thus a composition corresponding to a mixture of about 30 per cent. of a saturated silicate of protoxyd of iron, (with small portions of lime, magnesia, and alumina,) and 70 per cent. of magnetic oxyd of iron.

Wuth's analyses.

From this it appears that a large part of the ore added to the pig metal is not consumed, but passes off in the slag; and it would seem that, in this case, the principal action of the oxyd of iron had been the removal of the oxydized silicon. Each unit of silicon furnishes by its oxydation an amount of silica which requires at least four units of iron, in the state of protoxyd, for its conversion into the ordinary fusible silicate of iron. All of this oxyd of iron, in the ordinary puddling-process, except so far as furnished by the fettling, must be derived from the oxydation of the metal, and hence the great waste with highly siliciferous cast iron in the puddling-furnace. For such irons, therefore, the Ellershausen process would seem to be especially adapted.

Silicious iron.

Were the conversion of the iron to take place according to the formulas already given, solely by the action of the oxyd of iron on the carbon and silicon of the pig metal, 100 parts of this, having the composition above assigned, should yield theoretically, supposing no subsequent loss of iron by oxydation, or otherwise, 111 parts of pure iron; since to the 95 parts present in the pig metal, would be added 16 parts reduced from the oxyd, by the carbon and silicon. In practice, however, the gain is much less than this, leading to the conclusion that a part of the carbon is oxydized by atmospheric oxygen, while much of the added iron-oxyd must escape

Theory of the process.

unreduced, in the slags, as we have seen is really the case. According to Dr. Wuth, the result of the treatment of nearly 4000 tons of iron by the Ellershausen method, as above described, with about 28 per cent. of oxyd of iron, showed a gain of not quite 5 per cent. on the weight of the pig iron employed.

These conclusions are confirmed by recent results of the iron-works of Messrs. Burden, at Troy, New York, where the Ellershausen process has been found to give satisfactory results, with 15 per cent of magnetic iron ore, although the quality of the product was improved when 20 per cent. of ore was used.

Suggestions for  
practice. ;

Analyses of the pig metal, the ore, and the products, in such trials will be most important as serving to shed farther light on this new process. Meanwhile the following suggestions with regard to it seem warranted by the facts before us. 1st. The ore used should be as free as possible from impurities. Silicious matters, by uniting directly with the oxyd of iron, occasion a large loss of ore; while lime, magnesia and alumina-compounds, not only increase of the bulk of slag, but render it pasty and difficult to be removed from the iron. 2nd. The ore should be finely divided, inasmuch as more surface will thus be presented to the iron. In the working of the process at Pittsburg, much of the ore added was in coarse grains, which escaping, dissolved in the slag, but otherwise unchanged, caused this to be, as we have seen, extremely rich in oxyd of iron. The coarse grains, it may be supposed, serve however to give to the aggregate that mechanical condition which is favorable to the proper working of the process, a result which would probably be equally well secured by the admixture of a portion of charcoal; an experiment, which I am informed, has already been successfully tried at Pittsburg. The use of a greatly reduced proportion of finely divided and very pure ore, together with a portion of coarsely ground charcoal, would therefore seem to promise the best and most economical results with the Ellershausen process. Rich hematite, free from silica, or magnetite, previously calcined, and if necessary, purified, after crushing, by the aid of a magnetic machine, should be tried. The magnetic portion of the fine iron sands from the lower St. Lawrence would probably yield excellent results in this process. Some experiments made at Pittsburg, in which the purified iron-sands were used in place of the ordinary ores, are said to have given a superior result. The ores used in the trials which gave the pig metal by Dr. Wuth, were, however, the magnetite of Luke Chapman, with some hematite from Missouri.

Choice of ores.

From what has been said, it will be evident that the supply of air in the furnace should be as abundant as in the process of puddling, and that a reducing or feebly oxydizing atmosphere therein, would either greatly modify the conditions of the Ellershausen process, or lead to failure.

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The novel invention of Ellershausen, on which his patent is based, is the mixing of crushed or pulverized ore with the molten metal, as it flows from the blast-furnace or cupola, thus forming masses of conglomerate, which are subsequently exposed to heat in a reverberatory furnace. The mingling of the two, was, in the first experiments, effected by pouring them simultaneously into an ingot-mould, while the mixture was stirred with a wooden pole. This method, however, is replaced by an ingenious arrangement of a large horizontal turning-table, around the periphery of which is a trough, divided, by partitions, into a series of compartments, into which the ore and the liquid metal are simultaneously discharged. The table being made to revolve, each compartment receives, in succession, a thin layer of mingled ore and metal, more or less intimately mixed, and the process is continued until the moulds are filled; when the consolidated masses, composed of successive layers, not over four tenths of an inch in thickness, are removed, and are ready to be placed in a common puddling or other reverberatory furnace. Here, at a white heat, if the proper conditions have been observed, the conglomerate softens, without melting, the slag begins to flow out, and the iron is soon ready for the operations of squeezing and rolling.

Turning table.

Advantages of the process.

It is claimed for this process for the production of malleable iron, that it requires much less time than puddling; the average time required for the treatment, in an ordinary single puddling-furnace, of a charge of 800 pounds of the conglomerate, producing about 600 pounds of muck-bar, not being over an hour and a quarter. The consumption of coal is reduced about one-half, and the ordinary labor of the puddler is done away with, the masses in the furnace requiring but little manipulation. The rapid wearing of the furnace-bottom, which in puddling, causes such a loss of time, is also obviated. In addition to these advantages, which in Pittsburgh, it is claimed, effect a saving of eight or ten dollars a ton, it is found that the iron produced in this way is superior in quality to that obtained from the same pig metal by the process of puddling. This superiority is apparently explained by the fact, established by Dr. Wuth's analyses, is the sulphur from the pig metal is more completely eliminated by the Ellershausen process than by puddling. The analyses, with a summary of the report will be found in the *Chemical News*, American edition, in the supplement for October, 1869; and with Dr. Wuth's report, in full, in Osborn's *Metallurgy of Iron*, page 565.

The Ellershausen process is now regularly worked at Pittsburgh, by Messrs. Shoenberger and Co., and in one or the other places in the United States; and in the opinion of some who are best qualified to judge, is destined to general adoption. Its introduction has been retarded by various causes, among which are the jealousies of puddlers, and, in some cases, by partial failures, the probable causes of which have been pointed out in the preceding pages.

Granulated  
iron.

Numerous patent-claims, from that of John Wood, in 1761, down to the present time, have been based upon the use of granulated or pulverized cast iron for the production of steel or malleable iron. The iron is granulated by beating in large mortars, when heated nearly to its melting point, or by causing it to fall into water, through the air, or upon a rapidly-revolving disk, from which it is thrown off by centrifugal force. The grains of iron, more or less oxydized at the surface, are directed to be conveyed to a furnace, and there formed into lumps for the rolls or hammer; or else mixed with oxyd of iron, and exposed to heat in a furnace, (or in close vessels) whereby a malleable iron, fit for the manufacture of steel, is obtained. See, among others the specification of Bousfield, in 1857, No. 3082, and that of Morgans, in 1865, No. 806, of the British Patent Office. In so far as these propose to work in the open furnace, they differ from the old method of Wood, and the Welsh process, already described, page 299, and approach to the conditions attained in the Ellershausen process. Excellent results have recently been obtained by Mr. Hewitt at Ringwood, New Jersey, by mixing the granulated cast iron, with iron ore in grains, and exposing the mixture to heat on the hearth of a reverberatory; when decarbonization, and conversion to malleable iron takes place, as in Ellershausen's method, without fusion.



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